BRITISH
MANUFACTURING INDUSTRIES.

BRITISH MANUFACTURING INDUSTRIES.

EDITED BY

G. PHILLIPS BEVAN, F.G.S.

ACIDS, ALKALIES, SOAP, AND MINOR CHEMICAL PRODUCTS,

BY PROFESSOR CHURCH, M.A., F.C.S (The Agricultural College, Cirencester)

OILS AND CANDLES,

BY W. MATTIEU WILLIAMS, F.C.S., F.R.A.S.

GAS AND LIGHTING,

BY R. H. PATTERSON, F.S.S. (late Metropolitan Gas Referee).

SECOND EDITION.

LONDON:
EDWARD STANFORD, 55, CHARING CROSS.

1877.

PREFACE.

The object of this series is to bring into one focus the leading features and present position of the most important industries of the kingdom, so as to enable the general reader to comprehend the enormous development that has taken place within the last twenty or thirty years. It is evident that the great increase in education throughout the country has tended largely to foster a simultaneous interest in technical knowledge, as evinced by the spread of Art and Science Schools, Trade Museums, International Exhibitions, &c.; and this fact is borne out by a perusal of the daily papers, in which the prominence given to every improvement in trade or machinery attests the desire of the reading public to know more about these matters. Here, however, the difficulty commences, for the only means of acquiring this information are from handbooks to the various manufactures (which are usually too minute in detail for general instruction), from trade journals, and the reports of scientific societies; and to obtain and systematize these scattered details is a labour and a tax upon time and patience

which comparatively few persons care to surmount. In these volumes all these facts are gathered together, and presented in as readable a form as is compatible with accuracy and a freedom from superficiality; and though they do not lay claim to being a technical guide to each industry, the names of the contributors are a sufficient guarantee that they are a reliable and standard work of reference. Great stress is laid on the progressive developments of the manufactures, and the various applications to them of the collateral arts and sciences; the history of each is truly given, while present processes and recent inventions are succinctly described.

BRITISH MANUFACTURING INDUSTRIES

THE MANUFACTURE OF ACIDS.

By Prof. Church, M.A., F.C.S., The Agricultural College, Cirencester.

I. Oil of Vitriol, or Sulphuric Acid.

The importance of this manufacture can hardly be exaggerated. Sulphuric acid is used in so many arts and processes, that its extensive production and employment in a country may be taken as a measure of the degree of civilization. Of the useful materials which are obtained by the use of this acid I may mention, as well-known examples, soda, soap, chloride of lime, and glass. But, in fact, the employment of this acid is essential to the preparation of countless matters useful in metallurgy, in dyeing and calico-printing, in medicine, &c. To such uses of sulphuric acid I shall have repeated occasion to refer in the following pages.

Although the common process in use for the preparation of oil of vitriol (another name for sulphuric acid) has been carried on for upwards of a century, it is neither the original method of making this substance, nor is it one simple and easily understood. The

original oil of vitriol was really distilled from a kind of "vitriol,"—the name given to certain salts or compounds containing a metal, derived from sulphuric acid. Such vitriols are—blue vitriol, or sulphate of copper; white vitriol, or sulphate of zinc; and green vitriol, or sulphate of iron. This last compound has long been employed at Nordhausen, in Saxony, for the preparation of a remarkable kind of oil of vitriol, which fumes in the air, and is much denser than the ordinary sort. As it is extensively used for dissolving indigo, in preparing certain baths for dyeing blue, I will briefly describe its manufacture here, before speaking of the more complex operations involved in the preparation of ordinary sulphuric acid.

The green vitriol is first of all dried, to remove most of the water of crystallization: at the same time a considerable quantity of oxygen is absorbed from the air, and thus in the subsequent distillation, less sulphurous acid gas (sulphur dioxide, SO_2) is given off and lost, since some ferric sulphate is formed. The next step is to heat the dried green vitriol in small fire-clay retorts, with charges of about 2½ lb. apiece. The first distillate consists of weak sulphuric acid containing some amount of sulphur dioxide, and is thrown away. Then the receivers, each containing about an ounce of water, or of common sulphuric acid, are luted on to the retorts, after the heat has been raised and white fumes of sulphuric anhydride begin to appear. The distillation proceeds for twenty-four to thirty-six hours, while four repetitions of the process with fresh charges are requisite before the

distilled acid attains the requisite strength of 1·88 to 1·92 specific gravity. The acid thus made fumes in the air, is generally of a pale brown colour, and has the approximate composition of 1 molecule of sulphuric acid and 1 of sulphuric anhydride (or H_2SO_4, SO_3). It is twice as effective in dissolving indigo as ordinary oil of vitriol, and is, unlike that acid, usually free from lead, but always contains traces of iron.

Experiments have recently been made to produce fuming sulphuric acid by modified and improved processes. As the value of this powerful solvent becomes more appreciated, its manufacture will no doubt be carried on in this country.

COMMON OIL OF VITRIOL.

The whole of the vast quantity of sulphuric acid manufactured in Great Britain is prepared by a process of French origin, invented by a calico-printer of Rouen, and improved by the eminent chemist Chaptal. The earliest sulphuric acid works were erected by Dr. Roebuck, of Birmingham, who introduced the process about the year 1746, and then built the first "lead chamber," for carrying it on at Prestonpans, near Edinburgh. The chemistry of the process is not yet thoroughly understood, but the conditions of a successful manufacture can be easily fulfilled. It must be premised that sulphuric acid cannot be made at once by the direct union of the three elements which it contains. If this were the case, nothing more would be needed than to burn sulphur in the presence of an ample supply of atmospheric air and of steam. But in

this way an acid called *sulphurous* is obtained, differing wholly from sulphuric acid in its properties, and containing one atom of oxygen less. To introduce that atom of oxygen is the difficulty. It has to be done by the agency of what may be termed an "oxygen-carrier," a substance which has a sufficient attraction for oxygen to absorb it from the air, and yet does not enter into so fixed an union with it, as not to permit it to form fresh combinations. Nitric acid and several of the oxides of nitrogen are capable of fulfilling this function. Thus in the manufacture of sulphuric acid we have to employ the materials here given—

(1) Sulphur, or a substance capable of yielding sulphur dioxide (sulphurous acid gas) when burnt;

(2) Atmospheric air, to supply the necessary oxygen;

(3) Water, in the form of steam, or water-spray.

(4) Nitric acid, derived from the action of a small quantity of oil of vitriol on a small quantity of sodium nitrate. This nitric acid soon becomes changed, yielding certain oxides of nitrogen which answer the same purpose, viz. that of carrying oxygen.

I shall proceed to consider in order the several materials just named, their sources, and manner of employment.

(1) First of all, as to the sulphur used. Formerly native sulphur, chiefly imported from Sicily, was the sole foundation of this manufacture, the quantities sent thence into the United Kingdom amounting to 19,122 tons in 1833, to 38,654 tons in 1838, and to 1,152,111 in 1867. But after the King of Naples had granted (in 1838) a sulphur monopoly to a French company, great

efforts were made to find other sources of sulphur, and even to recover the acid used up in certain manufactures. Pyrites, a natural compound of 1 atom of iron and 2 atoms of sulphur, and containing when pure more than 53 per cent. of the latter element, was extensively introduced, and is now most successfully employed, as is the sulphur from the spent iron oxide which has been used in purifying coal-gas.

If sulphur be used, it is burnt on an iron floor supported by brickwork, and heated by a small fire at first to start the combustion. The door through which the sulphur is introduced has shutters in it for the regulated admission of air, while the gaseous product of the combustion is led away through a flue either directly or indirectly into a large leaden chamber. The admission of the requisite amount of air may be regulated by machinery, but it is usually left to the skill of an experienced workman. If pyrites be used instead of native or distilled sulphur, a different form of burner or furnace is needed. Sometimes a cascade burner is used, when the pyrites is burnt in falling; but more often it is shaped like an inverted cone, and has holes for the entrance of air both at the bottom and top. The first action of the heat applied to start the combustion of the pyrites is, to sublime a portion of the sulphur, a new iron sulphide being left behind. But the sublimed sulphur meeting with oxygen from the upper range of openings in the cone, is there burnt, while even the residue on the floor of the furnace gradually loses its sulphur, through the oxidation caused by opening the lower set of holes and closing the

upper, becoming at last the iron oxide known as rouge or rust. Sometimes this substance contains enough copper to be worth treating for the extraction of that metal, or even of the silver occasionally present in paying quantities; this residue may also be afterwards employed for purifying gas, for iron smelting, &c. The quantity of pyrites, of native sulphur, or of recovered sulphur, with which the burners are charged from time to time, will depend upon the size of the chamber of lead on the floor of which the oil of vitriol is condensed, and upon the number of furnaces or burners which feed such chamber. For a chamber 16 feet high, 20 broad, and 120 long, 12 cwts of sulphur (or nearly twice that quantity of pyrites), divided into six charges, will be required; but it must be remembered that slight changes in the apparatus employed, or the conduct of the various operations involved in the manufacture, may considerably alter the rate at which the sulphur can be consumed. This point will be referred to farther on.

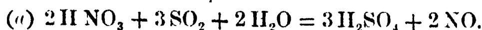
(2) As to the atmospheric air necessary to supply the oxygen for the combustion of the sulphur or pyrites, its admission into the burners has been already described. But a further quantity is required before the final product can be formed. Each atom of sulphur (by weight 32 parts) will take up 3 atoms of oxygen (together weighing 48 parts) and 1 molecule of water (weighing 18 parts) to make one molecule of oil of vitriol. Two-thirds of this necessary oxygen are taken up in the burners; the remainder is subsequently admitted, as into the leaden chamber, &c.

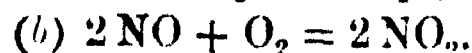
When pyrites is used as the source of sulphur, a still larger amount of oxygen will be requisite, for the iron as well as the sulphur must be combined with this element. If a kilogram of free sulphur, in order to convert it into oil of vitriol, require the oxygen contained in 5300 litres of atmospheric air, then the same weight of combined sulphur, as it occurs in pyrites, will require the oxygen furnished by some 6600 litres of air.

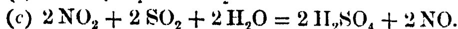
(3) The third material necessary to the formation of oil of vitriol is water; this is introduced in the form of high-pressure steam, which is admitted, in regulated amount and at different levels, into the leaden chamber. Quite recently, water-spray, blown in by steam, has been used, and is becoming appreciated. This plan, due to Spreugel, saves one-third of the coal.

(4) The fourth requisite is nitric acid. This substance has a very singular function to perform, and it does not enter in any way into the final product of the manufacture, and so differs entirely from the three materials previously considered. The office of the nitric acid used is, to carry the oxygen of the atmospheric air to the sulphur dioxide, a transference which it effects in the presence of water. Ultimately it is found that 2 molecules of nitric acid lose 1 molecule of water and 3 atoms of oxygen, and therefore suffice to turn 3 molecules of sulphur dioxide into the trioxide, which, in the presence of water, forms the same number of molecules of sulphuric acid. But this is not all; for there will be a residue of

2 molecules of nitric oxide produced in the above changes, and this gaseous product has the power of absorbing freely the oxygen of the air, becoming thus changed into nitric peroxide, a gas in which there is twice as much oxygen as in nitric oxide, but which yet gives up this amount to sulphur dioxide, again forming nitric oxide. This action goes on continuously, the same nitric peroxide losing oxygen to the sulphur dioxide only to regain it once more from the air. The mutual actions of the several materials just named may be readily expressed in three chemical equations; but the chemical changes which occur are more numerous, than it is here needful to give:


(a) $2 HNO_3 + 3 SO_2 + 2 H_2O = 3 H_2SO_4 + 2 NO$.


(b) $2 NO + O_2 = 2 NO_2$.


(c) $2 NO_2 + 2 SO_2 + 2 H_2O = 2 H_2SO_4 + 2 NO$.

The nitric acid necessary to start these changes is furnished by means of the action of a small quantity of previously-prepared oil of vitriol upon some nitre or sodium nitrate, contained in iron pots on the floors of the burners or suspended in the gaseous current. The quantity of nitrate consumed may be diminished in several ways, and should not exceed 4 or 5 per cent. of the sulphur burnt, and may even be reduced as low as 3 parts to every 100 parts of sulphur used. I shall now briefly describe the actual process of the manufacture of oil of vitriol from the materials just mentioned.

The gas from the sulphur or pyrites burners is led first of all into a tower packed with coke, through

which oil of vitriol (from the remotest lead chamber of the series of chambers) is allowed to trickle. This acid is charged with nitrogen compounds, such as nitrous acid and nitric peroxide, and these are quickly removed from it by the action of the ascending current of warm burner-gas, charged as it is with abundance of sulphur dioxide. Here it is that the great economy of the modern manufacture of sulphuric acid generally takes place, since these valuable nitrogen compounds would not only have been left in the acid and have rendered it impure, but would of course have been lost, so far as their power of oxidizing further quantities of sulphur dioxide was concerned. The denitrified acid from the "coke scrubber," or "Glover tower," flows into a reservoir, considerably concentrated by the passage of the hot gases through it, while these latter travel forward to the leaden chambers. These chambers are constructed of sheet lead supported upon a stout framework of wood. All the joinings of the lead are made by simple fusion, without the use of solder, while straps of lead are used to keep the various parts of the roofs in position. The size of the chambers varies greatly, but they have often a capacity of 50,000 feet to 100,000 feet or even more, those used with pyrites-burners being larger than the others. Some chambers are 300 feet long, 20 feet wide, and 15 feet high, and are divided by "curtains" or partitions of lead, so fitted alternately to the roof and the floor, that the burner-gases, the steam, and the air are compelled to pass under the roof curtains and over those attached to the floor, and

thus become very thoroughly mixed. Where a series of small undivided chambers exists, they are connected together by means of leaden tubes. In order to afford a weekly yield of 10 tons of oil of vitriol, a chamber having the capacity of about 35,000 cubic feet is requisite. Whatever size or internal arrangement be adopted for the chamber, the further process of manufacture is pretty much the same. The mixed gases—air, steam, &c.—having a temperature somewhere about 200° Fahr. or 93° C., re-act, as already described, upon one another in the chambers, and condense as sulphuric acid upon the floors, which have been previously covered, to the depth of 3 or 4 inches, with weak sulphuric acid or with water. White crystals of complex constitution are now and then produced in the chambers, when the supply of steam is insufficient.

The oil of vitriol formed on the floors, or "chamber acid," should not be allowed to become concentrated beyond the degree indicated by a specific gravity of 1½ times that of water, and is oftener withdrawn when its strength is but 1·35. Its state of concentration is ascertained from time to time by means of small leaden outlets from the chamber floors, known as "drips." Chamber acid may be at once used without concentration in the preparation of nitric acid, sulphates of ammonia and soda and certain manures; for most purposes, however, further treatment is required. Before describing such treatment, I must return to the spent or waste gases of the lead chambers, as they issue from the last of the series. They are led into a

"Gay-Lussac tower" or "coke scrubber," where they come into contact with concentrated oil of vitriol, to which they give up the nitric oxide and other nitrogen compounds which they contain. The nitrified sulphuric acid thus obtained is used in the "Glover tower," already mentioned, for washing the "burner-gas." It should be added, that the spent gases of the last lead chamber should consist chiefly of nitrogen, nitric and pernitric oxides, and a few per cents. of oxygen.

For many purposes in the arts and manufactures, the crude oil of vitriol requires either concentration or purification, or both. Concentration, or the more or less complete removal of the excess of water, may be commenced in shallow leaden pans, resting on plates or bars of iron heated directly by a fire from below. A less satisfactory plan consists in allowing the flame of a reverberatory furnace to play directly upon the surface of the acid; but in this method impurities are introduced, and some of the material is lost in the current of vapour and gas. The plan of throwing hot dry air through and over the acid has also been tried, but has not met with general approval. In leaden vessels the oil of vitriol may be concentrated until it has reached the specific gravity of 1·71, but beyond this point, the metal is rapidly dissolved, while sulphur dioxide is given off. Vessels of glass, or preferably of platinum, are employed in the final stage of this process. These vessels assume the form of retorts or stills, and, if of glass, are bedded in rows in a sandbath and heated, not from the bottom, but at the sides.

When sufficient water has been distilled, the remaining acid may be drawn off by a refrigerating siphon of platinum, or it may be distilled over at a still higher temperature. The most concentrated acid possible is a liquid of oily consistence, excessively corrosive, greedily absorbing moisture from the air, and becoming very hot when suddenly mixed with water. At a temperature of 60° Fahr., or 15°·5 C., it has a specific gravity of 1·842; when diluted with water, its specific gravity is diminished at the rates shown in the following table, the temperature being 15°·5 C.

Percentage of real acid. H_2SO_4.	Specific gravity
100	1·842
90	1·822
80	1·733
70	1·615
60	1·502
50	1·399

Theoretically, 256 lb. (or kilograms) of real sulphuric acid should be produced from 100 lb. (or kilograms) of sulphur; but in practice there is usually a loss of somewhere about 5 per cent. of the possible product.

I have before stated, that the chamber acid and the concentrated acid are impure. In the latter, as met with in commerce, we always find lead and generally arsenic, the former metal being derived from the material of the chambers, the latter from the pyrites employed, this mineral seldom containing less than half per cent. of that element, and often much more. When the strong acid is diluted with water, nearly all the lead comes down as sulphate, while the purer but

weaker acid may be siphoned off and concentrated. The arsenic may be removed as sulphide by the action of sulphuretted hydrogen or of barium sulphide upon the acid. Hydrochloric acid may also be found in oil of vitriol, originating in the common salt with which the soda-nitre is often contaminated. Nitrous compounds are likewise occasionally present.

Sulphuric acid is usually drawn off into large globular glass vessels with short necks, known as carboys, which are packed with straw in osier baskets. The corks may be protected from the acid by a previous boiling in melted paraffin, or by a coat of sulphur. The carboys hold about 11 or 12 gallons of acid, weighing 175 to 190 pounds.

The quantity of oil of vitriol annually produced in this country, though already vast, is continually increasing. Much of that made is, however, not sold, but employed at once on the spot for the preparation of salts, acids, and manures. So at one superphosphate works near London, where bones and other phosphatic substances are treated with oil of vitriol, the yearly production of this acid has often amounted to no less than 15,000 tons (having the specific gravity 1·60). It is impossible to give an estimate of the total annual production of sulphuric acid in the United Kingdom. But it may be concluded that the amount used is very large, when it is stated that 400,000 tons of pyrites were used in 1869 for its manufacture. A small work will produce 150 tons each year, and a large work from 1000 to 4000 tons. It may be broadly stated, that sulphuric acid plays a corresponding part in chemical

arts and industries to that of iron in engineering work.

In what I have said about oil of vitriol, I have described the two processes in actual use, without referring to other methods of making this acid which have been suggested from time to time, but which are not now in actual operation. One of these methods consists in passing sulphur dioxide along with air over platinized asbestos, or over bricks which have been treated with blue vitriol or with chromium sesquichloride, and then heated. Thus the SO_2, is oxidized, and by subsequent union with water yields the desired acid. Another process consists in the reaction of sulphur dioxide, chlorine, and water; another in the mutual action of gypsum and lead chloride; and in a fourth, alumina, water, and salt cake are made to interact.

II. Hydrochloric Acid and Bleaching Powder.

§ 1. *Manufacture of Hydrochloric Acid.*—For many years a great part of the hydrochloric (muriatic) acid, given off as a by-product in the manufacture of soda compounds from common salt, was allowed to escape. By the Alkali Act of 1863, 95 per cent. of the acid produced in the works must be condensed, though in practice it is seldom that 1 per cent. escapes condensation. The injury to farm crops and general vegetation by the admixture of traces of this acid with the atmosphere is very serious, and it becomes necessary to watch very narrowly the apparatus, &c., of the works in which it is produced. The process of manufacture

is a simple one, and is thus conducted. When sulphuric acid (specific gravity 1·78) is heated with common salt (sodium chloride) in cast-iron retorts over a furnace, hydrochloric acid comes off as a gas, which may be at once passed through a coke scrubber or tower in which water continually falls. The acid gas dissolves in the water, and thus the crude commercial acid is formed. A purer acid may be made by passing the acid gas into glass or stoneware vessels containing pure water and plunged into a cooling tank. The gas which escapes absorption in the first receiver passes on to a series of similar vessels, and finally the residual gas is sent into a coke tower, as already described, or into a leaden chamber, where a fine spray of cold water condenses the last portion of the acid gas. As it is found that about half the hydrochloric acid that can be made from a given weight of common salt comes off at a low temperature, it is customary in some works to divide the operation into two parts, performing the mixing and preliminary warming in one vessel, called the "decomposer," and completing the operation in another, called the "roaster," placed in a hotter part of the furnace.

Commercial hydrochloric acid has a yellow colour, due to ferric chloride (perchloride of iron) and often contains other impurities, such as chlorine, sulphuric acid, and arsenious chloride. When perfectly pure, and seen in large bulk, it has a pale greenish-yellow colour. It has a caustic sour taste, and gives off hydrochloric acid gas, which produces white fumes by condensing the moisture of the air. The strongest

acid of commerce is nothing more than a saturated solution of the true gaseous acid in water, and contains more than half its weight of water. The following table gives the percentages of real acid contained in the watery solutions, having the undermentioned specific gravities:

Specific gravity at 20° C.	Percentage of true acid (HCl).
1·21	42·9
1·20	40·8
1·15	30·3
1·10	20·2
1·05	10·1
1·025	5·05

The chief consumption of hydrochloric acid is in the production of chlorine and bleaching powder, in the manufacture of chlorides, in the preparation of glue and gelatine, in metallurgy, and in many processes of the chemical laboratory. It is almost exclusively made by the process which I have described, or by a nearly identical method, in which other chlorides, as those of potassium or magnesium, are substituted for sodium chloride. It may, however, be made in other ways, as for instance by the mutual action of common salt and steam at a high temperature, or by the conjoint action of sulphur dioxide, air, and steam upon common salt.

§ 2. *Manufacture of Chlorine.*—Chlorine and two or three of its compounds are very effective in destroying organic colouring matters, and those injurious volatile matters which are given off during the decay of animal and vegetable substances, or the poisons characteristic of special diseases. Not only is chlorine useful as a

bleacher and disinfectant, but it is employed in many metallurgical operations for the extraction and purification of metals. An example of this use may be found in Miller's process for toughening gold, by the passage of a stream of chlorine gas through the molten metal, when the silver, antimony, &c., are removed as chlorides, while the gold resists the attack. Owing to its gaseous state and comparatively slight solubility, chlorine is not sold except in certain forms of combination, chiefly in the shape of bleaching powder, which is at once the most portable, the most economical, and the most effective bleaching and disinfecting compound of chlorine that can be prepared on a large scale. I shall, however, here consider, in the first place, the modes in use for preparing chlorine itself, since this substance forms the starting point of the manufacture of bleaching powder.

Although many different materials, containing a high proportion of oxygen, may be used to set free the chlorine from common salt, or from potassium or magnesium chlorides, yet in practice the native black oxide of manganese or "wad" is almost the sole material actually in use for this purpose on a large scale. The other substances which have been proposed or used are certain chromates and nitrates, while in one method, ordinary copper chloride was mixed with some sand and then heated, until it had become converted into a lower chloride, giving off half its chlorine in the change. But, after all, the great improvements which have been effected in the process of making chlorine have not been in relation to the main materials of the

manufacture, but in their economical use and continued recovery for further operations.

In Mr. W. Weldon's old process for the manufacture of chlorine—a process which is worked largely—the manganese ore is treated with common hydrochloric acid in a still, and heated with a steam jet, when a partial neutralization only is effected, owing to the dilute condition of the acid. The cold liquid is then run into a well, when a chalk cream, a mixture of calcium carbonate and water, is added, until the free acid is neutralized, and the iron and aluminum present are precipitated as hydrates along with some gypsum. When the liquor has cleared itself in a settling tank, it is seen to have a faint rose colour, and now consists of two chlorides, those of manganese and calcium dissolved in water. With this solution the subsequent operations are conducted. First of all, it is run into the "oxidizer," and heated by steam to a temperature of between 130° and 170° Fahr. Then air is blown in, and at the same time milk of lime added, until the greater part of the manganese is not merely precipitated, but oxidized as well. The brownish-black mud which forms and settles, contains at first about 2 lb. of black manganese oxide (dioxide) per cubic foot, but soon becomes more compact, and twice as rich in that ingredient for the same bulk. This manganese mud is either stored, or else immediately run into a still by a shoot, and submitted to the action of crude hydrochloric acid, when the reaction again occurs which took place on treating the crude ore with acid—



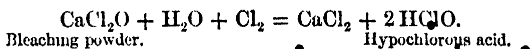
$$MnO_2 + 4\,HCl = MnCl_2 + 2\,H_2O + Cl_2.$$

Thus the manganese chloride is reproduced along with the desired product, chlorine, and is ready to be submitted to the same treatment as before, and to go through the same changes. The only loss in the process is that of the portion of chlorine which combines with calcium in the neutralization of the liquors, but the manganese is not lost, while its continual re-oxidation is cheaply effected by the simple process of blowing in common air. The plant required to carry out this process is costly, but the operations are conducted without difficulty. The novelty and importance of Weldon's improvements in this earlier process will justify a brief description of the various parts of the apparatus used in both his systems, so that the economy of the later method may be better appreciated. In the first process, just described, the still spoken of is constructed of silicious stone, generally Yorkshire flag, and is built square. The angles are made perfectly water-tight by means of india-rubber cords, while the whole is banded outside by iron. There are several openings into this still, such as a man-hole luted round with clay, and used for the introduction of the materials; a hole for the steam pipe; and another for the india-rubber tube through which the acid flows. A stone-ware tap at the bottom of the still serves to draw off the liquor, while at the top there is an exit pipe of stone-ware, for the delivery of the chlorine produced; this and other stone-ware pipes used are frequently heated in tar and pitch before use, to prevent them from cracking when suddenly cooled by rain, &c. The well, named before, is of cast iron, and is large

enough to hold all the contents of the still. The "settlers" are likewise of iron, and are from four to six feet every way. The oxidizer is commonly a cylindrical iron vessel, 12 feet in diameter and 22 feet in depth; two iron pipes go first to the bottom of the oxidizer: one large one, to supply the necessary air, and a smaller one for steam.

I will now describe Weldon's new process, which effects a nearly complete saving of the chlorine in the by-products, as well as of the manganese. In order to commence operations, the manganese ore is heated with hydrochloric acid in a still, and by means of steam. Some quantity of strong chlorine gas is thus let free, but, of course, the remainder of this element remains as manganese chloride in the residual solution. This liquor is then to be completely neutralized with magnesium carbonate (in the form of magnesite), or else with calcined magnesia, and finally contains the chlorides of manganese and magnesium. If the solution be boiled down till its temperature reaches 300° to 320° Fahr., hydrochloric acid will begin to come off. When this happens, it is to be run into the "double-blind furnace," in one part of which it is heated until dry, and in the other the dry residue is piled up in thin cakes, the temperature being then raised to blood redness. At the lower degree of heat, and so long as water is present, hydrochloric acid is evolved; but when the temperature is hotter, and air is admitted, then chlorine itself is given off, and magnesium manganite remains behind. This substance may be regarded as a compound of magnesia and manganese dioxide, and

is at once available for use in the still a second time. Of course, the chlorine which comes off during its production in the furnace is not concentrated like that of the still, for it is diluted with the nitrogen of the air blown in, but, though weak, it may be used directly for the preparation of bleaching powder or potassium chlorate. The hydrochloric acid evolved in the earlier stage of the process is condensed in a coke scrubber, and the liquid product formed is subsequently used in the reaction with the magnesium manganite. Thus, in the three forms of concentrated chlorine gas, of hydrochloric acid, and of dilute chlorine gas, this new process yields all the chlorine of the original hydrochloric acid used, save the small quantity which is inevitably lost through leakage, and imperfections in the mode of carrying on the manufacture. There are several complexities in the process which conduce to this result. One of these is the mode of concentrating the weak chlorine from the furnace operations above described. It is passed through two condensers or towers, where it comes in contact with milk of lime, and forms a solution of bleaching powder; then, by the further action of chlorine, this solution yields calcium chloride and hypochlorous acid:



$$\underset{\text{Bleaching powder.}}{CaCl_2O} + H_2O + Cl_2 = CaCl_2 + \underset{\text{Hypochlorous acid.}}{2\,HClO}.$$

The resulting solution of calcium chloride and hypochlorite is best used by pumping it at once into the "octagons" (vessels in which potassium chlorate is made), where it is treated with potassium chloride. Another mode of utilizing the liquor is

to treat it with hydrochloric acid in a still, when it yields chlorine:



$$HClO + HCl = 2\,Cl + H_2O.$$

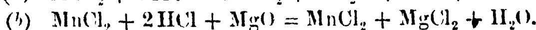
The whole plant of Weldon's new process is simple, easily managed, and comparatively inexpensive, and enables us to obtain practically all the chlorine of the hydrochloric acid used in an available form. One precaution is essentially necessary to success, and that concerns the temperature of the furnace in which the mixed chlorides are heated, in order to expel their chlorine. If the heat be too great, the chlorides fuse, and the air which enters does not penetrate the fused mass, and so the oxidation of the manganese into dioxide is arrested. It should be added, that the plant required for the Weldon improved process is the same as that for the old one, so far as the still, the well, and the settler are concerned. A deep cast-iron pot is also required (about the same diameter as the well, but much deeper), for boiling the neutral liquor, and, in addition, a kind of muffle furnace, with two beds or divisions quite separate from each other, but capable of being put into communication by means of a door worked by pulleys outside the furnace. The hydrochloric acid produced in the process may be condensed in coke scrubbers similar to those already described, but built of flag-stones, or in stone-ware pipes filled with porous silicious stones. The water for condensing gas is made to trickle uniformly downwards through pierced plates, perforated with holes one-eighth of an inch in diameter, and plugged loosely with wooden pegs. To utilize

the chlorine, scrubbers of similar shape are employed; but they are made of lead and are empty, while milk of lime instead of water is made to flow through them.

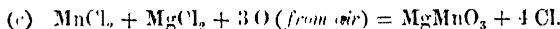
The following equations express the chemical reactions which occur in this new process of Mr. Weldon:

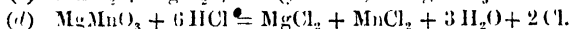
To begin the working,


(*a*) $MnO_2 + 6\,HCl = MnCl_2 + 2\,H_2O + 2\,Cl + 2\,HCl.$


(*b*) $MnCl_2 + 2\,HCl + MgO = MnCl_2 + MgCl_2 + H_2O.$

Afterwards, alternately,


(*c*) $MnCl_2 + MgCl_2 + 3\,O$ (*from air*) $= MgMnO_3 + 4\,Cl.$


(*d*) $MgMnO_3 + 6\,HCl = MgCl_2 + MnCl_2 + 3\,H_2O + 2\,Cl.$

Other processes besides Weldon's have come into use for the preparation of chlorine. Deacon's method consists in passing impure hydrochloric acid gas (from soda manufacture), mixed with air, over bricks soaked in blue vitriol, and heated to a temperature of about 700° to 750° Fahr.; not higher, at all events, for then cupric chloride is formed and vaporized; while at a temperature of 400° Fahr. the action ceases. Platinum, or green oxide of chromium, may be used instead of blue vitriol, and with effect, but the process requires great care, and the plant is both bulky and expensive; while the chlorine made in this way is so much diluted with the nitrogen of the air used, that it is difficult to make good bleaching powder with it. Practically this method does not yield nearly so large a quantity of chlorine from a given weight of common salt, as Weldon's improved pro-

cess does. Deacon has, however, patented a second method, in which salt cake (sodium sulphate) and chlorine are the immediate products of the action of sulphur dioxide and air upon common salt, but the reaction is by no means complete, nor is the process satisfactory. Many other methods, particularly as to the recovering of waste in the chlorine processes, have engaged the attention of chemists, and been carried out by manufacturers; such are Dunlop's, Gatty's, and Hofmann's plans. In Hargreaves' process, ferrous chloride is heated in a current of air, when ferric chloride is formed and decomposed with evolution of chlorine, and finally, nothing but ferric oxide (rouge) left.

Once or twice already in this article, I have introduced a notice of the production of bleaching powder, or "bleach," as it is technically termed. Invention has not been directed to any strikingly novel way of manufacturing bleach, but rather to the economical production of the chlorine necessary to its formation. Bleaching powder was ordinarily made by exposing slaked lime, spread in layers, not more than 3 inches deep, to the action of chlorine gas. The operation takes place in leaden or flagstone chambers, while the lime is spread on perforated trays. But with weak chlorine, that is, with chlorine gas mixed with nitrogen and useless gases or vapours, a depth of 3 inches for the layers of lime is almost too great, the under portions or layers of this earth escaping the action of the gas. In Deacon's chlorine process, a thin and greatly extended surface of lime must be

used, so arranged that the gas stronger in chlorine shall pass over the nearly saturated lime, and the weaker gas over that which is fresh. Other methods of utilizing weak chlorine have been devised. One of the best of these is Bramwell's, in which a series of cylinders, containing the lime, is so arranged, that the chlorine ascends through certain cylindrical openings, made afresh from time to time in the mass of the lime present, by means of the up-and-down motion of a series of wooden rods. In Hargreaves' plan, the lime itself gradually descends in an ascending current of chlorine. In the production of bleaching powder, great care must be taken to prevent the material from becoming too hot, or the action too rapid, for then calcium chloride and chlorate may be the chief products of the operation.

Bleaching powder is a white or yellowish-white powder, somewhat moist to the touch, and with a tendency to cohere into lumps. It contains a variable proportion of unattacked slaked lime and of moisture, while, as to the active constituent of it, two views are held. According to one of these views, the true bleaching agent in this preparation is the compound known to chemists as calcium hypochlorite (hypochlorite, or chloride of lime), which is associated with a single molecule of calcium chloride, the whole being thus represented: $CaCl_2O_2$, $CaCl_2$. As the trial has actually succeeded of isolating calcium hypochlorite from an aqueous solution of bleaching powder, we may consider that this compound is probably contained in, or, if not, is certainly formed from, the

material in question by the action of water. But according to the second view, bleaching powder does not contain any quantity either of calcium hypochlorite or chloride, but consists mainly of a chloro-hypochlorite, thus composed: $CaCl_2O$. It will be seen that the formula before given exactly corresponds to two molecules of this latter compound. It will be found that a good commercial sample contains about 26 or 27 per cent. of available or active chlorine, the whole of which is present in the solution made by rubbing 1 part of the bleaching powder with 10 parts of water. On filtering the mixture, a residue of lime is left, and a pale yellow liquid runs through, endowed with powerful deodorizing, disinfecting, and bleaching properties, but rapidly decomposing by exposure to sunlight or to heat. Even dry chloride of lime, kept in tightly closed casks, has been known to decompose rapidly, and with such violence as to cause an explosion, oxygen gas being abundantly given off. The bleaching and other properties of chloride of lime do not show themselves strikingly, unless the substance is decomposed by an acid. Even the carbonic acid of the air may slowly cause the liberation of chlorine, but it is more abundantly and rapidly evolved by the action of hydrochloric acid, in the following manner:



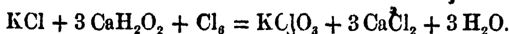
$$CaCl_2O + 2\,HCl = CaCl_2 + H_2O + Cl_2.$$

The free chlorine thus generated appears usually to act indirectly rather than directly in the bleaching and other purposes for which it is used, liberating the

oxygen of the water present by combining with its hydrogen. So bleaching by chlorine is in reality bleaching by oxygen.

It is impossible to estimate accurately the amount of bleach now annually produced in the United Kingdom, but in 1852 it was at least 13,100 tons, and in 1861, over 20,000; while more than 100,000 tons were made in England, by Weldon's process alone, in the year 1874. This increase is partly owing to the improvements in the economical production of chlorine which have been lately effected, but more particularly to the enormous demand for chloride of lime, not only for bleaching and calico printing purposes, but also for sanitary uses. Nor must it be forgotten that the utilization of straw, Esparto grass, and other fibrous materials for the manufacture of paper, involves a much larger consumption of bleaching agents than was requisite when linen rags were the sole basis of the pulp.

The compounds known as chlorates are so intimately connected in their origin with the manufacture of chlorine and bleaching powder, that a few words in reference to them may be appropriately introduced in this place. If 1 molecule of potassium chloride be dissolved in water, and then 3 molecules of calcium hydrate (slacked lime) be added, on the passage of excess of chlorine gas and the maintenance of a temperature not lower than 60° C. (140° F.), the following reaction ensues:



$$KCl + 3\,CaH_2O_2 + Cl_6 = KClO_3 + 3\,CaCl_2 + 3\,H_2O.$$

In actual practice, the following plan of working is adopted. The chlorine gas, made in one or other of the ways already described in the former part of this article, and either strong or diluted with nitrogen, &c., is passed into a vessel containing milk of lime, kept at a sufficient temperature either by the heat of the gas itself or else by jets of steam. When the lime is saturated with chlorine, the mixture is run off into a settling tank, which is lined with lead. Subsequently the clear liquor is drawn off into evaporating pans of lead, where it is boiled down, until all the chloride of lime present has been transformed into calcium chloride and chlorate. The next step consists in adding to the strong solution exactly that quantity of potassium chloride, which shall be adequate for the conversion of all its calcium chlorate into potassium chlorate. About 1 part of potassium chloride is employed to every 3 parts of lime taken. It should be added that waste, weak, or damaged bleaching powder forms a convenient material for use in this manufacture in lieu of the lime. The change which calcium chloro-hypochlorite undergoes, on being heated as above described, is thus written :



$$6\,CaClO_2 = 5\,CaCl_2 + Ca\,(ClO^3)_2.$$

Potassium chlorate affords a convenient material for the preparation of oxygen gas, as it is resolved into that element and potassium chloride, when heated above its fusing point. A mixture of ten parts of the salt and 1 part of perfectly dry ferric oxide (rouge) gives off oxygen at a comparatively low temperature,

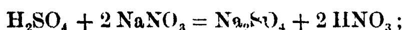
and with great ease. One grain of this mixture yields about 1 cubic inch of oxygen. The other uses of the chlorate of potassium are for oxidizing (as in calico-printing), for pyrotechny, for the preparation of certain fuse mixtures, and for the production of aniline black. Some of the other chlorates may be employed in fire-works, the barium chlorate burning with a splendid yellowish-green colour.

III.—Aquafortis, or Nitric Acid.

Nitric acid is obtained, like hydrochloric, by the decomposition of a saline compound by means of oil of vitriol. The manufacture of this liquid presents much less difficulty than that of sulphuric acid itself, or even of hydrochloric acid, but, owing to the comparative scarcity and costliness of the nitrates which form the basis operated upon, the cost of nitric acid is higher than that of the two acids just named. Nevertheless it is largely used in many industries, as in dissolving metals (such as silver), whereby metallic nitrates are formed; in oxidizing certain metals and even non-metals (such as sulphur in the oil of vitriol manufacture), and as a discharge in calico-printing; while of late years, this acid has been used in vast quantities for the preparation of a series of compounds known to chemists as "nitro" substitution products. These substances include—(1) nitro-benzol, nitro-toluol, and nitro-naphthalin, which constitute the main materials from which the so-called coal-tar colours originate; (2) gun-cotton, or tri-nitro-cellulose, and nitro-glycerine, the active

agent in dynamite; (3) picric acid, a nitro-derivative of carbolic acid, &c., much used for dyeing silk yellow.

Nitric acid is usually prepared from sodium nitrate (nitrate of soda, or Chilian saltpetre), a compound found in large quantities in Peru. When distilled with oil of vitriol, the nitrate is decomposed, sodium sulphate remaining behind, and nitric acid coming over. Retorts of iron or of glass are used, while the condensing and receiving vessels may be either of glass or stone-ware. One molecule of sulphuric acid reacts upon two of nitrate thus:



$$H_2SO_4 + 2\,NaNO_3 = Na_2SO_4 + 2\,HNO_3;$$

thus 98 parts of the acid are used to 170 of the salt (or 58 to 100). If twice as much acid be used, the reaction is very violent, and the lower compounds of nitrogen are formed largely, so that a good deal of the nitric acid is decomposed and lost, while the distillate is coloured. By mixing 100 parts sodium nitrate, 117 parts oil of vitriol, and 30 parts water, a crystallized acid sodium sulphate remains behind, and a colourless acid distils over. As the nitrate used is seldom completely refined, it contains 2 per cent. or so of common salt, and thus the earlier portions of the distillate are usually contaminated with hydrochloric acid, or rather, with chlorine. If the vapours first evolved be condensed in one set of coolers, and then, by means of a two- or three-way cock, the subsequent vapours be diverted into another set of condensers, the purer acid may be obtained separately and quite free from chlorine. Silver nitrate should

produce no cloudiness in this acid. This test may be applied, in order to ascertain when the impure acid has all come over; the last portions should also be collected apart, as they are sure to be contaminated with the lower oxides of nitrogen. Saltpetre, or potassium nitrate, may be used in lieu of the sodium salt, but it is more costly, gives less nitric acid for a given weight of salt taken, and demands the use of a molecule of sulphuric to each molecule of nitrate. On the other hand, plans have been devised for employing substitutes for sulphuric acid in the manufacture of nitric acid. Several sulphates, such as those of zinc and manganese, when heated with nitrates, decompose them: silica, manganese dichloride, and several other substances have been employed for the same purpose. But the older processes which I have described are by far the best, when care is taken to separate the less pure acid which comes over during the beginning and at the close of the distillation, and when an improved mode of condensing the vapours is adopted. In one of these plans, a kind of battery of stone-ware carboys is employed, so arranged (partly in vertical columns) as to intercept impurities, to effect complete condensation, and to act continuously with but little attention.

Pure nitric acid, HNO_3, is a colourless, densely fuming liquid, which boils at 86° C., and has the spec. grav. 1·53 at 15° C. Ordinary nitric acid contains 30 per cent. of water, has the formula $2HNO_3, 3H_2O$, boils at 120° C., and is of spec. grav. 1·42 at 15° C. The annexed table gives the percentage of real acid, the specific gravity, the boiling point, and the degrees

of Twaddell's hydrometer, of various strengths of nitric acid:

Per cent. real acid.	Specific gravity.	Degrees Twaddell.	Boiling point.
100	1·53	106	86° C.
90	1·49	98	100 „
80	1·46	92	114 „
70	1·42	84	123 „
60	1·37	74	118 „
50	1·32	64	115 „
40	1·25	50	110 „
30	1·19	38	107 „

Some idea of the quantity of nitric acid manufactured in this country may be gathered from the annual imports of saltpetre and cubic nitre, although a considerable proportion of these salts is used, at once, or after simple refining, for other purposes, such as the manufacture of gunpowder, the curing of bacon, and as manure for corn and grass crops. Of Chilian nitrate the imports during 1872 amounted to 83,000 tons, and in the first half of 1873, the imports at Liverpool alone were not less than 29,000 tons. There were also imported into Liverpool, 814 tons of saltpetre during the first half of 1872, and 913 tons during the corresponding period of 1873.

It is greatly to be desired that some practicable method of combining the nitrogen of the air with hydrogen, so as to form ammonia, could be devised; a reaction of the same kind capable of yielding nitrates would perhaps be still more desirable. At present, our power of making such compounds artificially from their ele-

ments can be accomplished only at great cost, and in the form of curious and difficult laboratory experiments. We do not even understand the conditions under which the native nitrates of the South American, African, Indian, and other great nitre beds of the world are formed. The price of the alkaline nitrates has risen greatly during the last few years, and still shows an upward tendency.

THE MANUFACTURE OF ALKALIES AND ALKALINE SALTS.

BY PROF. CHURCH, M.A., F.C.S., The Agricultural College, Cirencester.

I. POTASSIUM AND ITS COMPOUNDS.

THE very name of potash suggests the occurrence of this substance in the ashes of wood used as fuel. Chemical analysis shows, indeed, that the proportion of potassium compounds in the mineral residue or ash of land plants, though varying under different conditions of soil, species of plant, part of plant, or stage of its growth, is yet always very considerable. Even in many seaweeds the proportion of potash exceeds that of soda, though the sea-water from which they derive both these constituents is nearly ten times richer in sodium compounds than in those of potassium. But as the sources of the potash of all kinds of vegetation must be looked for in the mineral kingdom, we should expect to find some compounds of this substance in the earth's crust. On the other hand, as plants form directly or indirectly the sustenance of animals, these latter must also contain potassium compounds. It will be convenient then to consider the sources of this alkali and its compounds in the following order: mineral, vegetable, animal.

Mineral Sources of Potash.—At the present day the mineral sources of potassium salts must be regarded as most important. The occurrence of these compounds in some salt mines is a discovery of recent date, but has already created a most extensive manufacturing industry. At Stassfurt, in Prussia, situated some twenty kilometers from Magdeburg on the frontier of the Duchy of Anhalt, at Leopoldshall, and at Kulucz, in Hungary, a series of potassic layers occurs above the rock-salt proper. For a long time these upper layers were not known to be of any value, and were called *abraumsalz*, or "salt to be got rid of;" but at the present time (over twenty years having elapsed since their nature was discovered) the quantity of potash salts extracted from them at Stassfurt alone amounts to double the quantity of common salt obtained from the same mine. These potassic layers are, however, of rather complex and variable character, and contain large quantities of magnesium and sodium compounds, which have to be separated by special processes. It is interesting to note that the evaporation of sea-water gives in succession a series of salts, which in most particulars are practically identical with those occurring in the Stassfurt and similar salt mines. Arranging these latter compounds in the order of their successive deposition, we shall have the following series:

Stratum.	
Upper layer:	sylvine, tachyhydrite, boracite, carnallite, kainite.
Second ,,	rock-salt, with some kieserite and carnallite.
Third ,,	rock-salt, with veins of polyhalite.
Lower ,,	rock-salt, with veins of karstenite.

Of these minerals, there are only three which claim particular notice from our point of view. These are sylvine, or potassium chloride (KCl); carnallite, or hydrated potassio-magnesium chloride ($KMgCl_3$, 6 aq.); and kainite, which does not appear to be a distinct species, but generally contains about 36 per cent. of potassium sulphate (in commercial samples we find 25 per cent. to 28 per cent. of this salt), 25 per cent. of magnesium sulphate, 19 per cent. of magnesium chloride, and 20 per cent. of water. The sylvine or potassium chloride, when it occurs in sufficient amount, requires little or no treatment to fit it for use, beyond recrystallization from water. The carnallite, on the contrary, not only contains a large quantity of magnesium chloride, but is so deliquescent on that account, that it could not be conveyed from the place of production or exported, without great loss through liquefaction. For these reasons it is submitted to a purifying process, which is conducted as follows:

To every 4 parts by weight of carnallite, there are added 3 parts of the liquor resulting from the washing, or recrystallization, as the case may be, of the crude sylvine mentioned before. The solution of the carnallite is effected by means of superheated steam, and the vessels used often have a capacity of twenty tons. The steam, at a pressure of about 2 atmospheres, is admitted in such a way, as to assist in the mingling of the whole mass with the water, while a powerful stirrer effectually accomplishes this result. The solution thus obtained, after three hours of agitation and blowing in of steam, is allowed to settle for two days, and then forced into the crystallizing tanks, where it is made to

yield, by cooling, crops of coarse-grained crystals of crude chloride of potassium, containing 70 per cent. to 80 per cent. of that salt, after having been once washed. By repeated washing, and, of course, more completely by recrystallization, the purity of the product may be raised to 90 per cent. It should be added, that much of the original carnallite remains undissolved or but slightly altered in the first vessel in which the mineral was steamed, and is submitted in its turn to a repetition of the above process. From the mother liquors of the main crops of chloride of potassium, and from the wash-waters, further quantities of crude chloride are obtained by evaporation, &c.

Kanite is the third potash mineral found in the abraumsalz, which needs notice here. It is a dry, translucent, crystalline, straw-coloured substance, and has no tendency to deliquesce. Sometimes it is roasted to dry off the 20 per cent. of water present; but frequently it is exported it its native state, partly for use as an artificial manure, partly for the manufacture of pure sulphate of potash. Leopoldshall kainite, containing about 25 per cent. sulphate of potash, is sold in London at 3*l.* the ton, and in Liverpool at 2*l.* 10*s.* The quantity of potash salts raised from salt mines is enormous—Stassfurt alone giving over 500,000 tons in one year.

Another mineral compound containing potash is known as *orthoclase*, the common or potash felspar. This, however, is a most intractable mineral, for, unlike the Stassfurt salts, it is quite insoluble in water, and has to be submitted, at a very high temperature, to the action of a mixture of chalk, slaked lime, and a

little fluor spar, before it can be made to yield up its alkali. But the discovery of numerous other sources of potash has withdrawn attention from this mineral, and it would not pay to treat it, so long as other supplies of potash salts remain as abundant as they are now. Theoretically, potash felspar should contain 16·9 per cent. of oxide of potassium; not more than 12 per cent. to 14 per cent. is actually present however, the remainder of the alkali in it being soda.

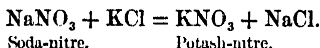
Nitre, saltpetre, nitrate of potash, or potassium nitrate (KNO_3), is an important substance, not so much on account of its being a potash salt, but on account of its being a nitrate; it may, however, be conveniently mentioned here. Its claims to be regarded as a true mineral are dubious, for it is generally formed in the presence of the débris of organic substances.

Nitre occurs in certain soils in Hindostan, Ceylon, Algeria, South Africa, Egypt, Persia, and Ecuador; about 15,500 tons were imported into England in 1875. A dry climate, and a hot season followed by rain, favour its production. The natural sorts usually contain other alkaline and alkaline-earthy salts, as well as the nitrate. And in some places the native nitre is in reality a nitrate of lime, not of potash, or a mixture of both these nitrates, and requires to be treated with wood ashes, before it yields the true salt. The conditions under which the formation of nitre occurs naturally, have been imitated in the artificial arrangements for the production of that substance, known as nitre-gardens.*

* It is stated that during the Franco-German war 2000 tons were thus made.

Much porous calcareous matter, a decomposing felspathic rock, a moderate amount of moisture, a high temperature, and plenty of vegetable and animal refuse, such are the chief points to be attended to. Whether occurring naturally or prepared artificially, the nitre-containing earth or compost is submitted to the same series of processes. These are (1) extraction with cold water; (2) addition to the solution thus obtained, of a liquor containing enough potash to change calcium and magnesium nitrates into the potassium salt, the liquors used for this purpose being obtained from wood ashes, or from some of the other sources of potassium carbonate named in this article; potassium sulphate is used occasionally where no magnesium compounds are present, or where they have been previously removed from the nitrous liquor by means of lime; (3) concentration and crystallization of the weak nitre solution prepared as above; (4) purification or refining of the first crop of crystals by recrystallization. In purifying saltpetre, advantage is taken of its much greater solubility in hot than in cold water, while the accompanying salts do not show so marked a difference. A very ingenious plan of making potash-nitre from the more abundant Chilian or Peruvian soda-nitre, has indeed been founded on this fact. First of all, the corresponding or equivalent quantities of commercial soda-nitre and commercial chloride of potassium are dissolved in water, the latter salt being made to dissolve completely before the nitrate is added. By the aid of heat the liquor is concentrated to a sp. gr. of 1·5, while the common salt which separates is

continually ladled out, the drainings and wash waters from it being, however, continuously returned to the cauldron. When the common salt ceases to separate freely, and the liquor still shows the sp. gr. named above, it will contain about one-fifth of its weight of saltpetre. On being allowed to cool somewhat, it will deposit a small further crop of common salt, which, forming gradually, will carry down many impurities and clarify the liquor. The mother liquor is left to crystallize in shallow pans, the crystals being first washed with cold water, and, in some cases, then re-crystallized. All wash-waters, &c., obtained in these operations are saved. The reaction which occurs in the conversion of soda into potash-nitre, is thus expressed chemically:



$$\underset{\text{Soda-nitre.}}{NaNO_3} + KCl = \underset{\text{Potash-nitre.}}{KNO_3} + NaCl.$$

Vegetable Sources of Potash.—Formerly the vegetable sources of potash were not merely of great importance, but were practically the only ones to which recourse was had for this valuable alkali. Now, the mineral supplies of potash and its compounds have reduced the manufacture from the ashes of plants to comparative insignificance; indeed, in many districts it has become extinct, while in others it is still produced as a by-product in the preparation of iodine, &c. The chief remaining places of manufacture are situated in those countries where considerable tracts of forest land still exist, as in many parts of North America, in Russia, in Germany, and in Sweden. But forest trees, though the most abundant in quantity, are the poorest

in the proportion of potash which they contain, as the following table shows.

One thousand parts of the under-named vegetable substances, mostly in their air-dried condition, contain:

Substance.	Total Ash.	Potash.
Beet molasses	93	66
Tobacco plant	198	54
Potato skins	67	48
Dutch rush	201	27
Ferns	59	25
Sedges	70	23
Malt dust	60	21
Poppy-seed cake	96	20
Hop plant	71	19
Linseed cake	55	13
Flax plant	32	7
Vines	23	7
Wheat grain	18	6
Elm	25	3½
Oak (branches and bark)	10	2
Beech leaves (55 per cent. water) ..	31	1½
Ash wood	12	1
Beech wood	6	1
Oak leaves (60 per cent. water) ..	20	¾
Oak wood (trunk)	5	½
Pine and fir wood	2½	½

Annual plants often contain more potash than perennials, the more succulent kinds and the youngest parts of various plants being richest.

When the vegetable matter has been burnt, either on the surface of the ground or in shallow pits, it is extracted with water in troughs or barrels, provided with false bottoms serving as filters, with taps below, and so arranged in series, that weak lyes come in contact with

fresh portions of ash, until they contain from one-fifth to one-fourth their weight of saline matters. The lye is now boiled down in shallow pans of cast iron, the loss by evaporation being made up by fresh additions of lye. Finally, the liquor becomes so concentrated, that it solidifies on cooling. The mass is then found to contain about 12 per cent. of water with some alkaline sulphates and chlorides, but it consists mainly of potassium carbonate (carbonate of potash, K_2CO_3). This material goes under the name of "potashes." Potashes may be refined into "pearl-ashes," by being heated strongly in a reverberatory furnace, or a muffle furnace, until the carbonaceous impurities have been burnt off, and of course the whole of the water removed. The salt, when colourless, is removed from the calcining hearth to the cooling hearth, and then broken into lumps, and packed tightly into well-made casks. This process however, though concentrating the crude product, and improving its appearance, yields a product which is far from pure, while some of the best pearl-ashes of commerce, which have been more completely purified, present a very different composition. Potashes prepared as above described, are found to contain from 40 to 78 per cent. of real potassium carbonate, and from 13 to 20 or even 40 per cent. of the sulphates. Now, by a more careful lixiviation of the ashes, by decantation from the sediment, and by a kind of fractional crystallization of the concentrated lye, most of the potassium sulphate may be separated.

A comparatively new vegetable source of potash

compounds has been turned to account of late years. The vast development of the beet-sugar industry has drawn attention to the various waste products of this manufacture. When the juice containing the sugar has been extracted from the roots, we have to deal with a solution which contains something besides sugar and water. After it has been clarified, and the crystallizable sugar extracted, the remaining liquor is permitted to ferment, that the uncrystallizable sugar may be turned into alcohol and so utilized. But in the stills there will yet remain a waste liquor, and it is in this that abundance of potash salts occur. By evaporating this liquor in a long trough, divided across into an evaporating and a calcining section, a salt is finally obtained, consisting of a mixture of potassium chloride, sulphate, and carbonate (together, 50 or 60 per cent.), with insoluble matter and a good deal of sodium carbonate. The potassium carbonate forms about one-third of the weight of the calcined mass, and arises in great measure from the destruction, during the calcining process, of the potassium oxalate, tartrate, and nitrate which occur naturally in the beetroot, and, consequently, in the liquor from the stills. The crude calcined potash salts are disposed of in different manners in different places. Sometimes they are turned into nitre, but often they are submitted to processes of purification, by which the chief salts present are separately obtained. By dissolving the mixture in hot water to a sp. gr. of 1·26, and allowing the solution to cool, potassium sulphate, accompanied by a little sodium carbonate, crystallizes

out. The mother liquor from this salt, concentrated to a sp. gr. of 1·41, gives another crop of crystals similar to the last, but richer in the carbonate. After this crop has been removed, the liquor is allowed to cool to 30° C., when potassium chloride separates. Subsequently, crops of sodium carbonate, and of a mixed potassium and sodium carbonate, are successively removed.

In wine-producing countries, much potash was obtained from wine lees, and from the crude argol, deposited as a crust in wine casks. Most of this is now employed for the manufacture of tartaric acid; one English firm alone annually using about 700 tons of argol and tartar for this purpose, besides a large quantity of wine lees: The potash salts might be saved as by-products in the manufacture of tartaric acid, but this is not always the case; still, the firm alluded to above turns out per year about 200 tons of potassium sulphate (of 90 per cent.) derived from tartar. Wine yeast, when dried, also yields some potash as carbonate, corresponding to about 10 per cent. of its weight.

The ashes of marine plants were once of great value as sources of potash and of soda. Early in the present century, the production of kelp in Scotland exceeded 20,000 tons per annum, while the value of a ton of Highland kelp was then about 20*l.* The introduction of Leblanc's process for turning common salt into other soda compounds has destroyed the value of kelp as a source of sodium carbonate, and now these ashes are worked only for iodine, and, incidentally, for

potassium salts. The manufacture is chiefly confined to some districts of Scotland and of the west coast of Ireland, and is still generally conducted in a somewhat rough and wasteful fashion. Mr. E. C. Stanford has, however, devised an ingenious method of distilling instead of burning the seaweed, and his process thus not only avoids loss of iodine, but affords the means of obtaining many additional products of value, including acetic acid, paraffin, illuminating gas, ammonia, and charcoal. Other improvements (as of washing the weed with water, &c.) have been suggested or occasionally adopted; but the following plan of merely burning the collected and dried seaweed, is that generally in use.

The weed, collected or cut in the summer months, is burnt on the floor of hearths or open kilns, about 14 feet in length, by 2 feet in breadth, and 1 foot in depth. The cheapest vegetable refuse locally obtainable is used as fuel to start the burning of the weed, but the combustion is not allowed to become too active. After some six or eight hours, the porous ash is heated more strongly, till it partially fuses down to form a kind of "floor." These operations are repeated with fresh charges of weed, until several such floors have accumulated. Finally, the whole hot mass is split up by throwing cold water upon it, and the fragments are then removed, packed, and sold for purification elsewhere, or are treated on the spot in the following way: The crude ash from the hearth is broken up and placed in vast, where it undergoes extraction with water, much in the same way as the crude potashes from land plants,

previously noticed, the insoluble residue being sold to glass manufacturers, or employed as manure (it contains both alkaline salts and phosphates). The liquor is then evaporated, until a crop of impure potassium sulphate crystals is first obtained: on cooling and standing, crude potassium chloride falls. Afterwards, on again being boiled down, a series of sodium salts separates, and then, on cooling the mother liquor of these, a second crop of potassium chloride falls: further concentration and subsequent cooling produce the same results again. In the final mother liquors the potassium iodide still remains in solution. The value of kelp, not merely so far as regards its iodine, but also its potash, depends partly upon the mode of preparing it which has been adopted, and partly upon the nature of the seaweed from which it has been obtained. Different species of seaweed vary much in their percentage of potassium compounds, the ash of some sorts containing twice as much as that of others. A ton of kelp may be worth 9*l.*, or less than 3*l.*

Although seaweeds often contain more potash than soda, it must not be supposed that the seawater from which they have derived both alkalies contains nearly as much of the former alkali as of the latter; 10,000 parts of sea-water will contain about ·26 parts of potassium chloride and sulphate, but not less than 240 parts of sodium chloride. Still, an ingenious process was devised by Balard, and improved by Merle, by means of which the separation of these comparatively small proportions of potash compounds can be effected. In the maritime districts of the south of France, this

process is conducted in what are known as "salt-gardens." In these, by an alternation of concentrations and refrigerations, common salt, sodium sulphate, artificial carnallite, and other compounds are successively deposited. The chief products of these salt-gardens, besides common salt, finally take the forms of potassium chloride and sulphate, magnesium sulphate or Epsom salts, sodium sulphate, and a residual mother liquor, from which bromine may be obtained.

Animal Sources of Potash.—Attempts have been made, chiefly in the south of France, to utilize the potash compounds contained in the yelk of sheep's wool. It was found by MM. Maumené and Rogelet, that an average merino fleece contains an amount of potassium equal to five ounces, or even more, of real potash. By the collection, evaporation, and incineration of the waters in which such fleeces are washed, immense quantities of potash salts might be recovered for use in agriculture as manure, or for ordinary applications in other arts. The wool of English breeds of sheep, however, is much poorer in yelk, and yields but a small fraction of the above-named amount of potash.

In the account just given of potash compounds, I have not entered very minutely into the processes by which perfectly pure products are obtained, although these are sometimes manufactured in this country on a very large scale. Especially is this the case with potassium carbonate, which is much used in a pure, or nearly pure, condition, for the manufacture of the best kinds of colourless flint glass, and for the preparation of some of those other salts of potassium which are

used in medicine and the arts. American pearl-ash is the chief material employed in the preparation of the pure carbonate. It is mixed with some clean sawdust, and then incinerated on the hearth of a reverberatory furnace. The fused mass, after cooling, is exhausted with water, the clear solution decanted from the insoluble residue, and again evaporated and incinerated. These processes are repeated a third and a fourth time; only, previous to the final evaporation, the liquor is concentrated, till the potassium sulphate has fallen as a crystalline precipitate. From the final mother liquor, by further concentration, a crystallized hydrated potassium carbonate may be obtained, and it is this salt which, by strong heating, yields a nearly pure, dry product. From it may also be made the best kind of another compound now largely manufactured in Great Britain, namely, caustic potash, or more correctly, potassium hydrate (KHO). A word or two about this useful substance may be here introduced. It may be, though not in a pure state, prepared directly from potassium sulphate, chalk, and coal dust, by strongly heating this mixture, lixiviating the mass with water, and evaporating the clear liquor; or it may be made from crude or purified pearl-ash, by caustifying these products with fresh-slaked lime, decanting the caustic potash liquor from the calcium carbonate thus formed, evaporating it, and removing the impurities as they separate. Finally, the concentrated liquor is dried up, the residual caustic potash fused, and cast into blocks or sticks in metal moulds. It may be whitened by blowing air through the fused substance, or by

adding a little nitrate. The product is a far more powerful caustic and detergent agent than the carbonate, but is applied also to many uses for which the latter salt is not appropriate.

The statistics of the production of potash salts and the trade in them, both British and foreign, are difficult of collection. I have already given a few figures relating to this industry, and now add some others. In 1867 we imported 10,730 tons of crude saltpetre (potassium nitrate), chiefly from Bengal. The imports of pearl-ashes and potashes into the United Kingdom amounted to 7189 tons in 1865, most of these materials coming from British North America; but some from other countries, as Russia, where the total production of potashes is not less than 11,400 tons per annum. The production of saltpetre in Germany in the year 1872 reached 5311 tons, while the immense quantity of 506,420 tons of the native crude potash salts (of Stassfurt) was then worked up in that country in thirty-three factories. These half million tons yielded 50,000 tons potassium chloride, 62,500 tons potash salts for manure, 2500 tons of potassium sulphate and carbonate, and large quantities of other salts.

I have been compelled, owing to the necessity for compression, to select a few typical potassium compounds only for discussion, leaving out of consideration many of great importance in the arts, such as potash alum, potassium dichromate, and potassium iodide.

II. Soda and its Compounds.

It would be difficult indeed to exaggerate the importance of the soda manufacture. Not only has this industry attained gigantic proportions, but its products and by-products are so numerous, and their applications so varied, that it affects our every-day life far more than we should be likely to imagine. To it we owe not only many preparations useful in medicine and other arts, but such common materials as glass and soap. Here I shall describe, as briefly as may be, firstly, the two chief natural compounds of soda, or rather of sodium, the metallic basis of all the substances called "soda salts"; and secondly, the most important artificial compounds of this element.

Common Salt.—This compound, called also sodium chloride, is by far the most abundant of all sodium compounds. It occurs under three circumstances: as the solid rock-salt of salt mines, in brine springs, and in sea-water—from all which sources it may, under certain conditions, be profitably obtained. Rock-salt occurs in many foreign localities, as Wieliczka, in Poland; Ischl, in Austria; Stassfurt, in Prussia; Cardona, in Spain; Bex, in Switzerland, &c., &c. In England it is abundant near Northwich, in Cheshire, but our home salt-field is of most limited area when compared with some of those on the continent of Europe. Colourless transparent rock-salt is very nearly pure sodium chloride (98 to 99 per cent.), though it usually contains traces of magnesium and calcium chlorides. Sometimes, however, it is penetrated by

veins of other minerals, or of earthy impurities. The strong solutions of salt and of saline matters found in Worcestershire, Cheshire, Shropshire, &c., in the form of brine springs, are also made to yield up much of their salt by evaporation and crystallization, but the products are seldom so pure as the best rock-salt, containing chlorides of other metals besides sodium, and sulphates as well. Still, such brines, chiefly those naturally occurring, but sometimes those artificially made by dissolving rough rock-salt in water, are the main sources of English salt. English natural brines contain about 25 per cent. of real salt, which is chiefly deposited on boiling them down. The coarsest grain salt is obtained by slow evaporation at a low temperature (100° Fahr.), and the finest table salt at the boiling point of the brine (226° Fahr.). In the Cheshire brine district the works are chiefly situated at Middlewich, Winsford, Marston, Winnington, and Northwich, lower down the river Weaver than the old locality of the salt works at Nantwich, and also near Sandbach, on the river Wheelock. Single manufacturers turn out annually as much as 50,000 or 70,000 tons of "white" salt, while the whole produce of the Cheshire district in brine salt and purified rock-salt is now more than 1⅓ million of tons per annum. The total amount of white salt produced in Great Britain and Ireland probably amounts to two million tons per annum. Much of this is exported, and much used in fish and bacon curing, and for domestic purposes. It has been calculated that the consumption of salt by each individual of the population is not less than 16 lb. per

annum. It will be recollected, however, that most of the rougher sort of salt is worked up into sodium sulphate, and ultimately into carbonate, at the alkali works.

The preparation of salt from sea-water is still carried on to some extent in Great Britain, but it forms a more important feature in the manufacturing industry of other and warmer countries. As sea-water contains but one-tenth the quantity of common salt present in natural brines (2½ instead of 25 per cent.), the process of extracting it is much more tedious, and requires far more heat. Then, too, sea-water contains much larger quantities of magnesium and potassium salts than brine, and so the production of a pure sodium chloride involves more complex operations. Salt water and brines may be concentrated economically by exposing them to the summer sun in shallow basins ("salt-gardens"), or by pumping them on to frameworks of timber filled with brushwood, protected from rain, but exposed as much as possible to the air. When a sufficient concentration has been thus attained, the remaining operations are performed by the aid of artificial heat in suitable pans, often of very large area, the first deposits, containing many impurities, being separated, and then the common salt; the mother liquor is afterwards worked for magnesium salts, for potassium chloride, and for bromine.

Nitrate of soda, the nitratine of some mineralogists, is, next to common salt, the most important native sodium compound. It goes under a variety of names, besides those given above. Sometimes it is termed

Chilian saltpetre, sometimes soda nitrate, and in the more exact language of chemistry, sodium nitrate. I have already mentioned it as the source of nitric acid, but here I shall say a few words as to its mode of occurrence, and its uses.

Soda-nitre comes chiefly from Northern Chili, where it occurs over a dry, elevated table-land, as an efflorescence upon the soil. The remains of marine shells attest the former presence of the sea, and account for the sodium of the compound; but it is difficult to explain how its nitric constituent has been formed, though it has been supposed to be traceable to the decomposition and oxidation of the nitrogenous matters contained in seaweed. It occurs as a yellow, deliquescent mass, containing very variable amounts of the pure nitrate, from 37 to 78 per cent. The other substances present in it are a little moisture and common salt, with some sodium sulphate and iodide, &c. It is refined roughly on the spot, and exported in continually increasing quantities from the seaports of Yquique and Valparaiso. Just now (at the close of 1876) it may be purchased in Liverpool for about 12*l.* a ton. The commercial salt should contain from 93 to 97 per cent. of real nitrate. It is employed in the preparation of nitric acid, of oil of vitriol, and of metallic nitrates; for the curing of bacon and other meat; in the compounding of blasting powder, in the manufacture of saltpetre, and as an ingredient of artificial manures, especially of those employed upon grasses and grain crops. The iodine present in the crude nitre is extracted from the mother liquors of the

refined salt, and forms a not unimportant source of profit. That the production of Chilian saltpetre is now very greatly increased, may be judged of from the amounts shipped in 1830 and 1870 respectively, namely, 935 tons in the former year, and 150,000 in the latter: in 1875, no less than 120,000 tons were imported into this country. In one district of Chili, about one square mile in extent, there are no less than eleven soda-nitre factories, together turning out, on the average, about 300 tons a day.

I can do little more than mention in passing two other natural sodium compounds, *borax* or *tincal*, and *natron* or *trona*. The former substance is a hydrated sodium borate ($Na_4B_2O_7$, 10 aq.), originally imported from India, and occurring in a lake in Thibet, but now also (in crystals) in the mud of Borax Lake, California, about 36 miles from the Pacific coast. It occurs also in the waters of that lake to the extent of 535 grains per gallon. Much is now made from the boracic acid prepared from the soffioni of Tuscany. It is extensively used in purifying and soldering metals, in glazing and enamelling porcelain and pottery, and in chemical analysis. Natron or trona, or sodium carbonate, occurs in the soda lakes of Egypt, and is mentioned twice in the English version of the Holy Scriptures under the term nitre. There are three native sodium carbonates known, two of them differing only in the amount of water present, and the third being the sesquicarbonate. Natron occurs as an efflorescence on the soil in many dry countries, especially in India, in Central Africa, and in Virginia, and it is also found

in the waters of many lakes and springs, the waters of Carlsbad giving about 700 tons per annum. But the native supplies of this compound sink into insignificance, when compared with its artificial production from common salt, which I now proceed to consider.

Manufacture of Caustic Soda and of the Carbonate.— Originally carbonate of soda was obtained chiefly from the ashes of marine and of maritime (sea-shore) plants. The substance thus prepared, and known as barilla, kelp, salicor, &c., seldom contained as much as a quarter of their weight of sodium carbonate, and often not more than 5 per cent. But by a series of processes, both caustic soda and the carbonate are now made from common salt, by a process known as Leblanc's method. We begin by turning the salt into sulphate by the action of oil of vitriol, obtaining hydrochloric acid as a by-product, as already described (page 14) under the heading of that acid. Next, the sodium sulphate is turned into crude soda, by roasting it with chalk and small coal; then the crude soda is purified; and finally, the sulphur, or part of it, is recovered from the soda waste. I proceed to give an outline of these latter processes, but the details would require far more space than I have at command. The salt cake, or crude sodium sulphate (containing about 87 per cent of neutral sulphate, 4 of acid sulphate, 5 of undecomposed common salt, and 4 of moisture and impurities), having been first made, is mixed with an equal weight of chalk, and about two-thirds of its weight of small coal, or glade; this mixture is fur-

naced together, and when the reduction is nearly complete, owing to the removal of the oxygen of the sulphate (Na_2SO_4) by means of the carbon of the coal, the product, called "black ash," or ball soda, is raked from the furnace into iron barrows or bogies, the masses or balls averaging 5 or 6 cwt. apiece. Burnt or over-roasted balls contain sodium sulphide, while green or under-roasted balls contain more than the trace of undecomposed sulphate which should be present. The careful workman will regulate the furnacing, so that the average amount of undecomposed sulphate in the ball-soda shall never exceed 1 per cent., and shall average about $\frac{3}{4}$ of a per cent. The chief ingredients of black ash are sodium carbonate and calcium sulphide, which together make up three-fourths of its weight; but it will also contain caustic lime, chalk, carbon, and a variety of other impurities, such as the undecomposed sulphate previously alluded to, and about 1 per cent. of sodium sulphide and hyposulphite. Of true soda (Na_2O) it should contain 25 per cent.

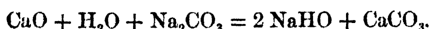
To purify the black ash from foreign matters, or rather to extract the sodium carbonate from it, the crude product is broken up into lumps, and then digested in vats with water at 111° Fahr. These vats are arranged in series, so that each fresh charge of black ash comes at first in contact with strong black-ash liquors, and finally with fresh water, and in this way nearly the whole of the soluble soda compounds are extracted. An immense number of other schemes have been devised for effecting this extraction as

thoroughly and economically as possible; but the principle involved in all is the same as that above named, the contact of fresh water with nearly exhausted ash, of weak lye with partially exhausted ash, and of strong lye with fresh ash. But with every care, in all the stages of the process, some soda is always lost, either by being left in the insoluble residue of the lixiviation, or by leakage, or by imperfect manufacture of the soda cake and furnacing of the ball-soda. The total losses thus caused amount to about 13 or 14 per cent. of the sulphate employed, and may even rise to 20 per cent. The lye or liquor prepared as above described is a solution containing much sodium carbonate, a good deal of sodium hydrate or caustic soda, and small quantities of chloride, sulphate, sulphide, &c.: it varies in specific gravity from 1·25 to 1·3. This lye is coloured by an iron compound, which may be removed by passing air through the liquor, or by the addition of a little green vitriol solution. There are three ways of treating the clarified lye. (1) It may be evaporated down to dryness, the final heating being effected on the floor of a reverberatory furnace. A mixed product is thus obtained, containing about

67	per cent.	sodium carbonate.
15	„	caustic soda.
17	„	other sodium compounds.

(2) The lye may be diluted (to 22° Twaddell), and then made caustic with burnt lime. For every ton of caustic soda to be obtained, about 15 cwt. of unslaked lime are used. The lime and the liquor are thoroughly

agitated by the aid of steam and air till the reaction has occurred :

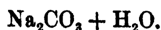


$$CaO + H_2O + Na_2CO_3 = 2\,NaHO + CaCO_3.$$

When the change is complete, and the carbonated lime has settled, the clear caustic liquor is run off, and boiled down in boat pans, where most of the sodium salts other than the hydrate are deposited: these are fished out and used with salt cake in the manufacture of black ash, while the precipitated calcium carbonate is employed in the same operation as a substitute for the limestone or chalk. The now very concentrated liquor is still further heated in cast-iron pots, called "finishers," till all water is expelled, and till the mass is fused and red-hot. The whitening of the caustic soda is then effected by oxidizing it, which destroys the sulphides, carbon, &c., to which its colour is due. Oxidation is best effected by blowing air into the fused mass; but sometimes the old method of adding sodium nitrate is still adopted; it is, however, difficult to avoid adding too much or too little of this salt for the purpose in view. Occasionally the agencies of air and of soda-nitre are employed together; when the latter substance is used alone, from 28 to 56 lb. are required for 1 ton of caustic. The white caustic alkali, still fused, is run into drums capable of containing about 5 cwt. From a "pot" of 8 tons caustic about 7 to 10 cwt. of a very crude discoloured soda will be obtained, technically known as "bottoms." These are sometimes sold, but they are often redissolved and worked up along with ordinary vat liquor or lye. The caustic soda obtained according to the above plan is

never pure, containing other sodium salts (as sulphate), together with the silicate and aluminate. Pure caustic soda can only be made by acting upon distilled sodium with water in a silver dish; the commercial caustic soda is usually reckoned to contain an amount of the hydrate or true caustic soda corresponding to 60 per cent. of the oxide (Na_2O); were it pure, it would contain 77·5 per cent. Caustic soda is used in soap making, in many chemical manufactures, in refining petroleum and paraffin, in the manufacture of sodium silicate or water glass, in the preparation of vegetable fibres for paper, and for an increasing number of minor purposes in the arts.

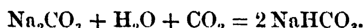
(3) The third method of treating the lye or liquor from the ball-soda has for its end the production of sodium carbonate. There are several modifications of the usual method of effecting this result. The vat liquor is evaporated as before, then dried up, ground to powder, and mixed with an equal bulk of carbonaceous matter, such as charcoal, slack, or sawdust. The mixture is then furnaced at a temperature about that of melting lead, the operation being called "calking," and being conducted in a "calker furnace." By subsequent solution in water and concentration, various crops of sodium carbonate more or less pure may be crystallized out: they will contain about 7 per cent. of water, if formed from a hot strong solution at a high temperature, and will then correspond to the formula



$$Na_2CO_3 + H_2O.$$

If, on the other hand, calcined soda be dissolved in

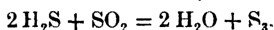
water, so as to make a solution saturated when hot, crystals of soda, or washing soda, will fall on cooling. By collecting and redissolving these, and giving the solution a week or more to crystallize, large and nearly pure crystals are obtained, but they contain 10 molecules of water, corresponding to 63 per cent. By slight alterations in the temperature and concentration of the liquor, other hydrates of this carbonate may be obtained with 15, 9, or 7 molecules in lieu of 10. By strongly heating any of these hydrates, anhydrous sodium carbonate may be obtained. The ordinary qualities of this salt are known as soda ash, or British Alkali. By passing a current of carbonic acid gas (carbon dioxide, CO_2) through a solution of the carbonate, or by exposing soda crystals to the air and the same gas, the so-called bicarbonate of soda is formed. It is in reality an acid carbonate, expressed by the formula $NaHCO_3$. It may be viewed as made up of the ordinary carbonate, of water, and of carbon dioxide:



$$Na_2CO_3 + H_2O + CO_2 = 2\,NaHCO_3.$$

Before saying a few words as to other ways of obtaining caustic and carbonated soda, the recovery of the sulphur from the so-called soda waste requires notice. In the soda manufacture a serious and almost total loss of sulphur will occur, unless it be recovered from the waste left in the vats, where the black ash has been lixiviated. Most of the sulphur exists in the form of calcium sulphide, or of a compound which may be assumed to contain that substance. By driving air or flue gases through the waste, or by simply exposing

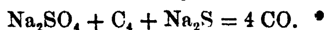
it to the air, some of this sulphide is oxidized into hyposulphite, while soluble polysulphides of calcium are also formed. When these changes have proceeded to the proper degree, ascertained by direct testing, the oxidized waste is lixiviated and the sulphur precipitated from the liquor thus obtained, by means of hydrochloric acid (generally by waste gases or liquors containing that acid). The chief actions which the acid causes are, the direct precipitation of some sulphur from the polysulphide and hyposulphite present, and the evolution of both hydrosulphuric acid (H_2S) and sulphur dioxide (SO_2). These two gases react upon one another mainly after this manner, producing much sulphur:



$$2\,H_2S + SO_2 = 2\,H_2O + S_3.$$

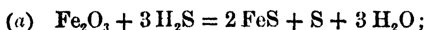
The sulphur is purified by being heated with water in a closed iron vessel by means of steam at about two atmospheres' pressure, and thus the sulphur melts and collects together at the bottom of the vessel. It is free from arsenic, a very general impurity in ordinary sulphur.

Returning for a while to the subject of soda, I may here refer to two or three processes which present valuable features, but which are at present of minor importance. Mr. Weldon, improving and developing a suggestion made in 1861 by Mr. Gossage, treats salt cake directly with small coal alone, furnacing the mixture in a muffle furnace. The reaction which ensues yields sodium sulphide and carbon monoxide, thus:

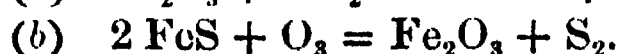


$$Na_2SO_4 + C_4 + Na_2S = 4\,CO.$$

The new product is, when cold, at once dissolved in water and treated in air-tight iron vessels with carbon dioxide, from any economical source, when hydrosulphuric acid is evolved and sodium carbonate is formed. The solution is run into vats, boiled, and crystallized: the product is nearly pure sodium carbonate. Or the liquor may be causticized with lime as already described, and so good caustic soda be obtained. We must now follow the course of the hydrosulphuric acid. This gas is led through a series of vessels containing hydrated ferric oxide, suspended in water, or through a solution of copper chloride. If the former material be used, the production of ferrous sulphide (FeS) and sulphur is the first result, and then air is blown through the mixture to peroxide the iron again, and to separate the sulphur from it. These two reactions are thus represented:



$$(a) \quad Fe_2O_3 + 3\,H_2S = 2\,FeS + S + 3\,H_2O;$$



$$(b) \quad 2\,FeS + O_3 = Fe_2O_3 + S_2.$$

These operations are repeated again and again till much free sulphur has accumulated, when the ferric oxide is dissolved out by acid, and the sulphur left.

An ingenious method of making the carbonate directly from the chloride of sodium has often engaged the attention of chemists and manufacturers. This plan depends upon the interchange of acid and base between ammonium carbonate and sodium chloride, ammonium chloride and sodium carbonate being the products. The reaction seems to occur most completely, when ammonia and carbon dioxide are together blown into a solution of common salt.

Soda is made from cryolite, a Greenland mineral, consisting of aluminium, sodium, and fluorine. About 15,000 tons of this substance are annually worked up by means of a process, in which caustic lime, either dry or in the form of slaked lime, is the agent employed to effect the decomposition. Caustic soda, sodium aluminate, and calcium fluoride are the three products of the action in the former case. The aluminate and caustic soda being both soluble in water, it is necessary to separate the alumina from the liquor. This is done by means of a stream of carbon dioxide, which carbonates all the soda, and precipitates the alumina. In the wet way, by using a sufficiency of slaked lime, all the soda is obtained in the caustic and soluble form.

As to the statistics of the manufacture of soda ash and other derivatives of common salt, we find, according to Mr. Gossage's report to the British Association, that in 1869, 326,000 tons of common salt were decomposed in Great Britain, 142,000 tons of which were treated in the Newcastle district, and most of the rest in the Lancashire district. According to Crookes' edition of Wagner's 'Technology,' Europe produced 592,500 tons of soda ash in 1870, 312,500 tons of this being made in Great Britain. In 1874 no less than 459,756 tons of salt were decomposed for alkali making in the Tyne and the Lancashire districts. The number of persons engaged in this most important industry is very great, but the data published are far from complete. In the 'Chemical Manufacturers' Directory' for 1874 we find but fifty manufacturers of soda ash given for England and one for

Scotland, a number far below the truth. One must say the same of the fifteen firms given as manufacturers of caustic soda, but not included in the previous list of soda-ash makers, though most of these latter send out caustic soda as well, and a good many of them soda crystals in addition. Of the less common sodium salts there are fewer makers, and these generally confine their attention to one or two salts only. I have not been able in my brief outline of the soda manufacture, to allude to these compounds, but they are of considerable importance, and employ much skilled labour. Amongst them I may name, sodium acetate, arseniate, bisulphite, manganate, permanganate, silicate, stannate, and phosphate.

III. Ammonia and its Salts.

At present no available method is known for combining the two constituent elements of ammonia, so as to make this compound by what might be called an *artificial* process. We are obliged to have recourse to matters of organic origin, chiefly derived from animals, but in one instance, and a very important one, from a substance—coal—derived from vegetable structures. When such matters as bones, skin, feathers, horns, &c., are submitted to a high temperature out of contact with the air, the elements present arrange themselves in new forms of combination, the nitrogen appearing chiefly as ammonia, or rather, as compounds of that base. This is the case in the manufacture of gas from coal; for coal, though containing but 1 part of nitrogen

in 100, and not yielding more than from one-third to one-half of that amount of ammonia, yet furnishes the larger proportion of the ammoniacal compounds met with in commerce. Thus, though coal is not distilled for the sake of its ammonia, yet it yields it as a by-product in quantities of no mean commercial importance.

Ammonia, in different states of combination, is used in many arts. In the caustic state, as a solution of ammonia gas in water, it is employed in medicine, in chemical analysis, in the preparation of many salts, in the extraction of cochineal, and in the preparation of colouring matters from lichens. It is also used, for the sake of the cold produced in its evaporation, in Carre's ice-making, and in other similar refrigerating machines. Ammonium sulphate, the sulphate of ammonia, is extensively used as an artificial manure, either alone or with other fertilizing substances; common alum is now made with it instead of with potassium sulphate, and it, in common with other compounds of the base, is employed in the preparation of caustic ammonia and certain ammonium salts.

Sal-ammoniac, or *Ammonium Chloride*, was first obtained by subliming the soot from the combustion of camel's dung, and was chiefly prepared in Egypt. It is now mainly procured in the purification of coal-gas. The following is an outline of one of the plans adopted for this purpose, a plan which, it will be seen, may be adopted with slight modification for the preparation of other salts of ammonium besides the chloride.

Gas water, the ammoniacal liquor resulting from the

F

destructive distillation of coal, is the material operated upon. It contains many substances besides ammonia compounds, and of these latter there are at least six different kinds, including the sesquicarbonate, the chloride, the sulphide and the sulphocyanide. Then, too, the presence of tarry matter and complex organic bases in the crude gas-water prevents the possibility of preparing from it, by direct addition of hydrochloric acid, anything like a pure sample of ammonium chloride. Thus it becomes necessary to liberate the ammonia present in various forms of combination by means of slaked lime, and to submit the alkaline mixture to some process, by which the ammonia, and the ammonia alone, shall be driven out, and subsequently collected in a pure state in water or acid. Three plans for effecting this separation have been proposed, and in one form or another are now used. The lime having been added in considerable excess above what is requisite to free the alkali, air may be blown into the liquor; or secondly, it may be similarly treated by means of a jet of steam, or of steam and air mixed; or lastly, the vessel containing the liquor and the lime may be heated by the direct application of fire or of hot flue gases. Whichever plan be adopted, the ammonia (NH_3), freed from its combinations, comes off, and after passing (if a very clean product be desired) through a purifier adapted for the retention of any traces of tar, is received into a series of cooled condensers, where it may be simply absorbed by pure water, or else allowed to combine with an acid. If hydrochloric acid be used, it may be introduced in

several ways, such as in solution in water, or in the form of air more or less charged with hydrochloric acid gas. In some manufactories, it is usual to employ water to condense the moist ammonia given off in the operation of distilling which I have described above, and to employ acids merely in a subsidiary manner, for preventing any loss of the volatile alkali through imperfect absorption. Every part of the absorbing apparatus requires, moreover, to be prepared and adjusted with scrupulous care, on account of the rapidity with which an immense volume of ammonia is absorbed and condensed suddenly by water or acid, and also by reason of the danger of loss through escape of the gas in imperfect joints and stop-cocks, or fromoverheating. It should have been stated above, that it is advisable to fit stirrers into the vessels where the lime and gas water are to be heated together, that the caking of the former on the bottom of the vessels may be avoided. And there are also numerous ingenious plans, by which fresh supplies of gas liquor are made warm in the very process by which they serve to cool and condense the moist ammonia, or ammonia and steam given off from the boiler. These last observations of course apply to those processes which are dependent upon the use of fire or steam for forcing out the ammonia from the liquor.

When ammonia, however obtained, has been exactly saturated with hydrochloric acid, nothing remains but to evaporate the solution of the chloride formed, either to the crystallizing point or else to dryness. In the former case, the crops of crystals are removed from

the mother liquor, drained and dried; in the latter, the dried mass is sublimed in large iron pots, and the vapours of the volatilized salt condensed in hoods or covers of iron or lead; vessels of glass or of earthenware may, however, be used for this purpose. The ammonium chloride, or sal-ammoniac of commerce prepared by sublimation, presents the appearance of a translucent mass of considerable thickness, in which numerous layers can be traced. It is never pure, and very seldom free from colour. It contains iron in the form of ferric chloride, and the chlorides of some compound ammoniums as well. It may be obtained free from iron by adding to the solid salt, previous to sublimation, about 5 per cent. of superphosphate of lime; or, if a solution is to be purified, enough ammonium sulphide is added to precipitate the iron as sulphide, which is then strained off or allowed to settle; the clear liquor, acidulated with a little pure hydrochloric acid, is now boiled down to the crystallizing point, any acid reaction being first neutralized with a little pure ammonia solution; which, however, must not be added till all smell of sulphuretted hydrogen has ceased.

Sal-ammoniac, when prepared directly from gas, is often obtained by allowing the tarry matters to be deposited, and then passing the gas through two scrubbers containing, in some works, 30 tons of stone (not coke). In these scrubbers the same water is used over and over again, till it has absorbed a sufficient proportion of ammonia. This gas liquor is strained and run off into tanks, from which it is siphoned into

vats made of wood lined with lead, or else built up of Yorkshire flags. These vats contain hydrochloric acid, which, when neutralized, forms a solution of impure sal-ammoniac. During the neutralization, the gases which are evolved are led through a fire, in order to burn off the hydrosulphuric acid which is present. The neutralized solution is strained to separate tarry matters, and then concentrated in pans furnished with covers and pipes. When sufficiently strong, it is run out into wooden tanks lined with lead in order to crystallize. The crystals are drained on a rack, so inclined as to allow the mother liquors to run back into the vat to be again worked up. The crude crystals are afterwards heated in cast-iron pans almost to the subliming point, by which treatment the tarry matters are driven off. Finally, the salt is sublimed in strong iron cylinders with leaden or iron covers lined with fire-clay. The sublimed sal-ammoniac forms dome-shaped masses in these covers.

Sal-ammoniac is used largely in metallurgical operations, especially in soldering, and in "galvanizing" and tinning iron. Its uses in the preparation of many chemical and pharmaceutical products are also numerous and important.

Sulphate of Ammonia, or *Ammonium Sulphate* $(NH_4)_2SO_4$, is prepared in exactly the same manner as the chloride, merely substituting sulphuric acid, more or less strong, for hydrochloric acid. Large quantities of very crude and rough sulphate are made directly from gas water, the product, though very impure and dark-coloured, being well adapted for agricultural use as an

artificial manure peculiarly applicable to grass and wheat. Theoretically, the absolutely pure salt should contain 25·71 per cent. of ammonia: practically, the sulphate used as manure often contains as little as 23 per cent. It is stated in Muspratt's 'Chemistry' that in one Glasgow factory 70,000 gallons of gas liquor are consumed weekly in the production of sulphate—the ammonia being distilled off, as before described, and the distillate being then slowly mixed with something like 4500 lb. of oil of vitriol of the strength of "chamber acid," about 1·625 in specific gravity. The mixture is then evaporated and crystallized. It is not unusual to find sulphate of ammonia from gas liquor largely contaminated with ammonium sulphocyanide. This salt must always be tested for, advantage being taken of the blood-red colour which persalts of iron (ferric chloride) strike with its solutions. As the sulphocyanide is not only useless to plants, but positively poisonous to them, any ammonium sulphate intended for agricultural use must be specially analyzed, by ascertaining not only its total nitrogen, but the amount of nitrogen existing as real ammonia. What is technically termed "gas ammonia" is much used in artificial mixed manures, and consists mainly of the waste sawdust from the gas purifiers, which having been first wetted with sulphuric acid, has then been made to absorb the ammonia of the gas which passes over it. It commonly contains, when withdrawn from the trays on which it has been spread in the purifiers, about 25 per cent. of real ammonium sulphate.

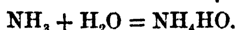
Another important source of ammonium sulphate (and consequently of ammonia itself and of its salts in general) is found in waste animal matter. The blood of slaughter-houses, bones, solid nitrogenous tissues, and urine may, by fermentation and the addition of lime, or else by destructive distillation, be made to yield up the greater part of the nitrogen which they contain in the form of ammonia. The free alkali may then be saturated with sulphuric or other acid, or may be used for the preparation of caustic ammonia solution. It is easy to distinguish the crude ammonia salts made from animal matters, from those which are prepared from gas water, by their peculiarly disagreeable odour.

Now that ammonium sulphate is so extensively used in alum making and for manure, &c., the gas liquor of most considerable gas works is utilized; but the same cannot be said for all other kinds of nitrogenous waste. The price of rough ammonia sulphate has varied much. Some twenty years ago it was sold at 8*l.* per ton: now it realizes 18*l.* It is found that 100 gallons of gas water yield about 50 lb. of this salt. Of course the yield of refined sulphate is less, since by solution in water of the crude salt, filtration through animal charcoal, and recrystallization, not only are impurities removed, but some true sulphate is unavoidably lost.

Carbonate of Ammonia, or *Ammonium Carbonate*, is, as already noted, a product of the distillation of coal for gas, and is also formed in the heating of most nitrogenized matters. The commercial compound is usually regarded as a sesquicarbonate, and may be

formulated thus: $4\,NH_3, 3\,CO_2, 2\,H_2O$. It was formerly made by the dry distillation of horns and bones, *and so its solution became known as hartshorn or* spirits of hartshorn. The pure dry salt constitutes the basis of common smelling salts; it is prepared in but small quantity from bones and animal matters, and then only as a by-product in the manufacture of animal charcoal, &c., the ammonium sulphate or chloride from gas being generally used to produce it by means of double decomposition, in the following way: An intimate mixture is made of 5 parts of the ammonium sulphate or chloride, 10 parts of calcium carbonate in the form of chalk, and 1 part of charcoal. Besides the solid sesquicarbonate of ammonia, which is the chief product of the reaction, free ammonia gas is evolved, and may be absorbed by leading it into water or an acid. The crude solid sesquicarbonate is purified by resublimation; 5 parts of chloride yield nearly 4 of carbonate.

Ammonia, caustic ammonia, liquor ammoniæ, or ammonium hydrate, as met with in commerce, is a nearly pure solution of ammonia gas in water. It is considered that this solution represents a definite chemical compound, thus:



$$NH_3 + H_2O = NH_4HO.$$

I have already described the main available sources of ammonia of vegetable and animal origin, and need do no more here than give an outline of the plan used for preparing the aqueous solution of this compound. The gas having been disengaged in iron or copper

vessels, as already described (under the heading "Sal-ammoniac," p. 65), is passed into a series of bottles with *three necks, partly filled with pure water kept cold. The first of the set is small and contains but little* liquid, as it serves as a kind of washer for the gas, but in the others the solution of ammonia is effected. One of the necks in each bottle is fitted with a safety tube. Sometimes the ammonia is absorbed in a kind of water-tank fitted with horizontal perforated shelves, the gas being admitted at the bottom and absorbed completely, before it can reach the top of the tank. Water expands greatly when it absorbs ammonia, so that 1 volume of water at 60° Fahr. (15°·6 C.), having dissolved no less than 783 volumes of the gas, has a specific gravity no greater than ·8849, and contains about 36 per cent. of ammonia. A convenient strength for ordinary use has a specific gravity of ·96, and contains 10 per cent. of ammonia. Commercial solution of ammonia always contains impurities, such as ammonium carbonate, empyreumatic oil, and compound ammonias. By adding a little slaked lime, and carefully redistilling it into water, the first impurity may be removed, and by *nearly* neutralizing it with acid, boiling down the salt formed, and submitting it once more to the original process of preparation, the latter impurities will be found to have been nearly wholly eliminated.

Besides the sources of ammonia and its salts already mentioned, there are others of which advantage may be taken in some parts of Europe. In the preparation of beetroot sugar, much ammonia is given off during

the evaporation of the juice, so that M. Renard has calculated that about 8 cwt. of ammonium sulphate might be prepared from each 100 tons of roots. In some volcanic regions, as in the Tuscan boracic acid lagoons, much ammonium sulphate occurs in solution, and might be utilized.

In the 'Chemical Manufacturers' Directory' for 1874, the names of twelve British makers of liquid ammonia, and of eighty-five makers of ammonium sulphate, and other salts of this alkali, may be found; but these numbers give no adequate idea of the multitude of ammonia works in this country, and much less do they indicate the great extent of this important industry. Ammonia and its salts, moreover, are often made in a factory only to be used up in other preparations, or in processes, without appearing for sale in the market; yet, after all, nearly fifty salts or compounds of ammonia will be found in the trade lists of chemical preparations issued by druggists.

THE MANUFACTURE OF SOAP.

By Prof. Church, M.A., F.C.S., The Agricultural College, Cirencester.

In chemical language, all the salts or metallic compounds of the fatty acids are called *soaps*, but the term is commonly restricted to the potassium and sodium salts of such acids. Thus we have "potash soaps," which are soft, and "soda soaps," which are hard. In pharmacy, however, there is another soap in use, which is really a "lead. soap," and which, though easily melted by warmth, is quite insoluble in water, and so differs in one most essential characteristic from the soaps employed for cleansing purposes. This lead soap, the material of which lead plaster is composed, is lead oleate, and is prepared by boiling litharge or lead protoxide with olive oil and some water, when lead oleate is formed and glycerine separates.

Hard soaps are commonly made with tallow and solid fats or oils and a lye of caustic soda. The following fatty materials of animal and vegetable origin are all used in the manufacture of either hard or soft soaps: tallow, South American beef-fat, Australian tallow, mixtures of animal fats ("kitchen stuff"), lard, fish oil, seal oil, palm oil, olive oil, cocoa-nut oil, cotton-seed oil, and a number of other non-drying oils and fats. Some of these latter are

termed "vegetable butter," and all of them, both fats and oils, are obtained from plants grown out of Great Britain, and either imported in the extracted condition, or, in the case of many oil seeds, pressed or dissolved out in this country. The residues of such vegetable matters are known as oilcakes, and several of them are largely employed in cattle feeding. Another material, not properly a fat, but capable of uniting with alkalies, is also used in soap making: I refer to rosin or colophony, the less volatile part of turpentine. The process of soap making or soap boiling may be conducted as follows; but I here describe one only of the numerous modes of operation in common use. The vessel in which the combination of fat and alkali is to be effected, is made of wrought-iron plates riveted together, and often of such a size, (15 feet diameter and 15 feet deep) that from 20 to 30 tons of soap may be produced from one charge. The heating of these soap pans or pots is accomplished by steam, which may be directly introduced into the mixture in the pan, or it may be led through it in a coil of pipe, or made to surround the pan in a jacket. Some of the oil or fat, or mixture of such matters, is first put into the pan, then some weak caustic lye (specific gravity 1·05 to 1·08) is added, the mixture being agitated and gently warmed at first, further quantities of lye, of increasing strength being added from time to time, and the heating continued until a kind of emulsion is formed. More fat (and rosin in making yellow soap), and then more lye is added from time to time, while the boiling is con-

tinued until the proper quantities and proportions of each have been introduced, and the *saponification*, or action of the alkali upon the fat, is complete. Precautions against excessive frothing and boiling over have to be taken, while the completion of the change must be ascertained by the occasional withdrawal and examination of small samples from the pan. The next step in the process is the separation of the soap from the mass of the liquor, a separation or parting which is commonly made by the addition of about 10 pounds of common salt for every 100 pounds of fatty matter employed. Soap being insoluble in strong saline solutions, separates in a nearly pure condition, floating to the top of the liquor. The layer of soap may be drawn off, still melted or fused, at this stage of the operation, and separates by further heating into a clear portion and a mottled portion; or the more usual plan may be adopted, of running off the spent watery and saline liquor below, leaving the soap in the pan to be afterwards treated in the following way. To the soap is added some lye, and the whole is once more heated, then the mixture is allowed to settle for some hours or even days, to drop the excess of lye, and to deposit the coloured impurities or "nigre." Next, the liquor is run off to be used in the next charge, while the soap, which now contains more water than before and a slight excess of alkali, is cast in iron frames or moulds, and, when cold, cut into blocks or bars by means of wires. The following kinds of soda soap may be distinguished.

1. White or curd soap, made chiefly from tallow.

2. Yellow soap, into the ingredients of which rosin enters.

3. Mottled soap, which contains grey or brown patches of impurities, chiefly sulphide and oxides of iron.

4. Castille or Marseilles soap, formerly made with good olive oil, and now prepared with the lower qualities of that oil, with olive fat, and with cotton seed and cheaper oils. The mottling is often produced in this soap, and in English mottled soap, by the use of a crude lye of caustic soda containing sodium sulphide and the addition of a little green vitriol solution.

5. Silicate of soda soaps, containing much water glass, or soluble alkaline silicate, and also a high percentage of water.

6. Fancy or toilet soaps, of many sorts, yet differing but slightly in composition. They are usually prepared from curd soap, by remelting and skimming it, &c. Perfumed soaps, for instance, are curd soaps remelted, with additions of fragrant essential oils, as those of bergamot, caraway, citronella, &c. In most cases colouring matters are also introduced, so as to make the product more pleasing to the eye. Glycerine soap contains, or should contain, a considerable amount of glycerine ($C_3H_8O_3$), the by-product previously spoken of as formed in soap boiling. Petroleum soap contains a little dark-coloured native rock-oil or petroleum, while from 5 to 20 per cent. of crystallized carbolic acid is introduced into carbolic

soap. Transparent soap is usually made by dissolving curd soap in its own weight of spirits of wine, adding some perfume, allowing impurities to settle, distilling off some of the spirit, and pouring the smooth and strong solution into moulds.

Pure soap, as it comes from the pan, is known in soapworks as "Genuine Pale": it contains, when quite fresh, about 7 per cent of soda, 63 of fatty matters and 30 of water. By keeping, it becomes drier and therefore stronger. A good soap for domestic use in its usual condition when offered for sale, should be firm to the touch, and contain in 100 parts not more than 10 of soda or 25 of water. It should contract but slightly, and that uniformly, when drying, and no efflorescence should appear upon it when kept in a dry place; this latter test being specially applicable to soaps which are intended to come in contact with the human skin. In making such soaps, the use of bone-fat, of essence of mirbane (that is nitrobenzol, and of such colouring matters as arsenical and copper green, and of magenta, &c., should be avoided.

Brown Windsor soap, one of the most popular toilet soaps, was formerly made with a soap formed from tallow, 2 parts, and olive oil, 1 part, oils of bergamot, cumin, thyme, and caraway being added to impart a scent, and brown umber and ochre to give colour. It is now often made from curd soap, by perfuming it and adding burnt sugar to give the brown hue; while other oils and fats besides those named above are often employed as the basis of its preparation.

Cocoa-nut oil, for instance, is much used in lieu of the more valuable fatty matters, as besides its cheapness it makes a hard soap, which still remains firm and solid, even when an unusually high percentage of water has been incorporated with it. The best shaving soap is made with oleic acid and potassium carbonate.

Soft soaps are essentially potassium oleate, but as they are not "parted," that is, as they contain all the glycerine and constituents of the lye, they are usually very impure. They are made by boiling fish oils, seal and whale oils, rape, hemp, linseed, and other vegetable oils with a lye, not of caustic soda, but of caustic potash, a little tallow being added in some cases to produce a speckled appearance in the finished product, known as "figging," from its resemblance to the seeds of figs. The process of boiling is conducted in the same way as with the hard soaps previously described, only the mixture of lye and fatty matter, when saponification is complete, is merely boiled down, with constant stirring, till much of the water has evaporated. When frothing has ceased, very large bubbles, which often overlap each other, form on the liquid, and then the product is said to "talk," a sign of the completion of the process. Soft soap generally contains not only much glycerine but an excess of alkali, and, being made from fish oils and other matters having an offensive smell, is used chiefly as a cleansing material in manufactures, such as that of woollen stuffs. The percentage of water in it is much higher than that found in hard soaps, being seldom less than 35 parts

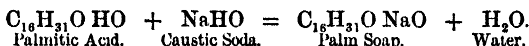
per 100, and often amounting to half the weight of the soap. In some cheaper kinds of soft soap, water glass, silicious earth, or china clay is introduced, but good qualities are made from such materials as gallipoli oil (a low quality of olive oil) and clean potashes alone. There is a growing tendency to add other and less costly materials, however; but if soaps were sold under a guarantee of approximate composition, so far as alkali, fatty acids, and water were concerned, the value of the article might be better estimated by the purchaser than it can often be now. In some cases these new materials added to soap for fulling purposes render it more effective, and must in so far be regarded as improvements. Under this head we may sometimes reckon the use of sodium aluminate, of water glass, of the mucilage of Iceland moss, this latter being a common seaweed, in which there is an abundance of a gummy substance, closely allied to the mucilage occurring in linseed.

A word or two may be added here concerning the chemical reactions and changes which occur during saponification, or rather which may be said to constitute that process. Soaps, as I have said at the beginning of this article, are the salts of certain fatty acids, which either occur in, or may easily be made from, the natural oils and fats. Only the soaps of the alkalies (potash, soda, and ammonia) are soluble, but others may be formed by the same kind of action, and some, such as lead soap, the soaps of zinc, manganese, copper, tin, mercury, silver, and aluminium, have been prepared for special purposes in some of the minor arts and industries,

while calcium or lime soap is formed whenever soap is used with hard water. Now the chemical formulæ of the three most usual and important fatty acids, and of their corresponding soda and potash compounds or soaps, are here given:

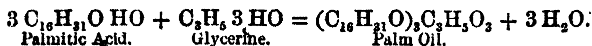
Palmitic Acid, $C_{16}H_{31}O\,HO$.	Stearic Acid, $C_{18}H_{35}O\,HO$.	Oleic Acid, $C_{18}H_{33}O\,HO$.
Sodium Palmitate, $C_{16}H_{31}O\,NaO$.	Sodium Stearate, $C_{18}H_{35}O\,NaO$.	Sodium Oleate, $C_{18}H_{33}O\,NaO$.
Potassium Palmitate, $C_{16}H_{31}O\,KO$.	Potassium Stearate, $C_{18}H_{35}O\,KO$.	Potassium Oleate. $C_{18}H_{33}O\,KO$.

These are the chief fatty acids, but several others are by no means of rare occurrence; such as arachidic acid ($C_{20}H_{39}OH\,O$) and hypogæic acid ($C_{16}H_{29}OH\,O$), from ground-nut oil; erucic acid ($C_{22}H_{41}O\,HO$), from colza oil and fixed oil of mustard, and linoleic acid ($C_{16}H_{27}O\,HO$), from the oils of linseed, walnut, poppy, and other drying oils. Now, if solid fats and liquid oils contained these acids in a free state, nothing would be easier to explain than their saponification, for the change would be expressed somewhat thus:



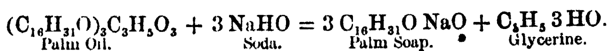
$$C_{16}H_{31}O\,HO + NaHO = C_{16}H_{31}O\,NaO + H_2O.$$

But though there are often more than traces of free fatty acids in natural fats and oils, animal and vegetable, yet they mainly consist of peculiar compounds known as *glycerides*, compounds which may be regarded as fatty acids, plus glycerine and minus water. Indeed, given palmitic acid and glycerine, palm oil may be artificially made, water separating in the operation, thus:



$$3\,C_{16}H_{31}O\,HO + C_3H_5\,3\,HO = (C_{16}H_{31}O)_3C_3H_5O_3 + 3\,H_2O.$$

Now the reverse change is that of saponification. Boil palm oil with soda lye, and you get palm soap and glycerine, thus:



$$\underset{\text{Palm Oil.}}{(C_{16}H_{31}O)_3C_3H_5O_3} + \underset{\text{Soda.}}{3\,NaHO} = \underset{\text{Palm Soap.}}{3\,C_{16}H_{31}O\,NaO} + \underset{\text{Glycerine.}}{C_3H_5\,3\,HO.}$$

Similar changes occur in preparing soaps from other glycerides.

According to a paper read, in 1870, by Mr. W. Gossage, of Widnes, before the British Association, the total production of soap in the year 1852 (when the soap duty was abolished) was not less than 1600 tons per week in Great Britain, less than half this quantity being produced in the Lancashire district. Since 1852 the expansion of this industry has been enormous, Mr. Gossage estimating it as having doubled, up to 1870, and calculating that the produce of the Lancashire district in that year equalled the whole quantity produced in Great Britain in 1852. In 1867 the declared value of soap exported amounted to 289,206*l.*, representing 219,372 cwt.

England, no doubt, stands still foremost in the manufacture of soap, an industry of which we may be justly proud, if the dictum be true, that the production of that substance affords a direct measure of civilization. As, however, the fats and oils, which are the more costly of the two kinds of materials used in soap boiling, are, in the main, imported into this country, it is chiefly to the cheap manufacture of soda that our activity in this industry is at present due. But if it should happen that our production of soap should fall below that of other nations, we may feel pretty sure that our con-

sumption of this commodity per head of the population will still remain as relatively great as it is at present. It should be mentioned, that soap boiling enables many waste, oily, and fatty residues and by-products to be usefully employed. Such matters are the tallow-oil removed by strong pressure in the preparation of hard fat from tallow, and the recovered grease from the washing of wool.

I have not entered into details as to the preparation of the lyes or alkaline liquors employed in the manufacture of soaps, as I have described what is practically the same operation in speaking of caustic potash and soda.

The preceding sketches of the larger chemical industries of Great Britain have necessarily been brief; but those readers who wish to obtain fuller information concerning these important manufactures will be able to learn much from the papers by Mr. Kingzett, now publishing in 'Iron.' I understand that these papers will be gathered shortly into a volume, under the title, 'History, Products, and Processes of the Alkali Trade.'

THE MINOR CHEMICAL PRODUCTS OF GREAT BRITAIN.

By Prof. Church, M.A., F.C.S., The Agricultural College, Cirencester.

Although the United Kingdom maintains its pre-eminence over all other countries in the number and magnitude of its vitriol and alkali works, yet this is far from being the case with respect to factories devoted to the finer and more delicate preparations of the chemist. Here German, French, and Austrian manufacturers are ahead of our own, and still continue to make remarkable progress. If a rare and curious substance, discovered by a scientific chemist, and made in his laboratory painfully, grain by grain, be found useful in medicine or dyeing, or some other art, straightway the foreign manufacturing chemist makes it, not by the ounce or pound merely, but by the hundredweight, or even by the ton. This is particularly the case with such chemical products as are generally called "organic" products, that is, those of which the element carbon is an important constituent. The success of foreign manufacturing chemists in this direction may be accounted for without difficulty. One reason is to be found in the cheapness of pure alcohol or spirit of wine, so necessary in the preparation or purification of most of the products to which I am now referring; but I cannot help thinking that the chief reason is of quite a different sort. To foreign chemical works a sound, well-trained, scientific chemist is attached, with a salary of perhaps 300*l.* or 350*l.* a year. Sometimes several such chemists are employed by one

manufacturer to improve old methods of manufacture, and to discover new ones. According to Dr. Lunge, one German chemical factory has six assistant-chemists (not practical managers), and one chief chemist, a distinguished man of scientific reputation, to whom is given a salary approaching 2000*l.* a year, simply for investigation and original work in the laboratory, not for superintending the manufacturing operations. Two points connected with the products of these continental factories are of special interest: one being the fact that much of the crude material necessary for making some of these products is exported from England for that purpose; and another point is that the original discoveries on which some of these industries have been based were made in our own country. But it must not be supposed that England turns out none of the finer and more exquisite products of the laboratory. One of the most original and brilliant chemical thinkers of the day, Mr. W. H. Perkin, the discoverer of mauve, was for a long time the chief of a colour work, second to none in the variety and beauty of its products. Howard's quinine, Hopkin and Williams' pyrogallic acid, and Macfarlane's opium alkaloids enjoy a well-deserved repute. Other names, scarcely less distinguished, might be here given. I propose, in fact, to illustrate some of these minor, yet most valuable and interesting, departments of chemical industry, by a selection of about a score of important substances, the names at least of which are familiar to the general reader.

The Preparation of the Minor Acids.—Acetic acid, or vinegar, is very extensively prepared in the United

Kingdom, partly by the older process of the oxidation of weak alcoholic liquids, and partly by the newer method of the destructive distillation of vegetable matter in the form of wood chips and shavings. Malt vinegar and wine vinegar are the products of the first-named change, while the wood vinegar obtained by the latter process is sometimes termed pyroligneous acid, though more frequently it is called vinegar, or even malt vinegar, when a little extract of malt has been added to it. In the preparation of acetic acid from alcoholic liquids, the action is one of oxidation, one molecule of pure or absolute alcohol taking up two atoms of oxygen, and producing one molecule of pure acetic acid and one of water, thus:



$$\underset{\text{Alcohol.}}{C_2H_6O} + O_2 = \underset{\text{Acetic Acid.}}{C_2H_4O_2} + H_2O.$$

Ten parts of alcohol by weight should yield just 13 parts of acetic acid, but some loss inevitably occurs. The alcoholic liquid must not be too strong (about 10 per cent. answers well), the temperature also must be kept between certain limits, as below 45° F. acetification does not take place, and at temperatures of 95° to 140°, though the action is rapid, much loss of alcohol, and of its products, aldehyde and acetic acid, occurs. Free access of air to the liquid is also essential, and the oxidation must be started by some substance itself undergoing change, or which can act as a carrier of oxygen, such as the vinegar fungus, or platinum black. In the preparation of acetic acid from wood, non-resinous wood (such as beech) is submitted to destructive distillation, whereby, while some charcoal remains behind, many new carbon compounds are

distilled over. Acetone, a volatile spirit, having a powerful solvent action on fats, is one of these; wood spirit, or methylic alcohol (CH_4O), is another; and a third and very abundant product is acetic acid. As acetic acid unites with alkalies to form fixed salts, the alkaline acetates, it may be separated from accompanying volatile matters by saturating the original liquid distillate with lime, distilling again to separate and obtain acetone and methylic alcohol, and then slightly roasting the residual calcium acetate (acetate of lime). Thus impurities are charred and made insoluble in water, while the calcium acetate is dissolved out by water, decomposed by sulphuric or hydrochloric acid, and again distilled. The names of twenty-nine manufacturers of acetic acid are given in the 'Chemical Manufacturers' Directory' for 1874, but this number is much below the truth.

Citric acid, the acid of many fruits, and notably of lemons, is made from imported products in considerable quantities. It is used in medicinal preparations, in dyeing and calico printing, &c. It is made partly from concentrated lemon juice, and partly from the crude calcium citrate, imported from Sicily and South Italy and France. One London manufacturer makes about 60 tons of crystallized citric acid every year, and has occasionally made as much as 100 tons. Calcium citrate is first prepared, and then this salt is decomposed by weak sulphuric acid, the citric acid being then set free. Citric acid is $C_6H_8O_7$, H_2O.

Tartaric acid, another vegetable acid, much resembling the citric, is made from wine lees and from argol, the deposit of wine casks, or from tartar. The manufac-

turing chemist alluded to in my last paragraph makes annually about 400 tons of tartaric acid, and once made as much as 478 tons in the year. There are but few makers of these two last-named acids in the United Kingdom. Both acids are applied to similar uses in the arts. Tartaric acid is $C_4H_6O_6$.

Oxalic acid not only occurs in plants (sorrel, docks, rhubarb) naturally, but may be readily made from vegetable tissues by a cheap process, that of heating such a material as sawdust with a mixture of caustic soda and potash; the operation is conducted thus: a strong solution of the mixed caustic alkalies (NaHO and KHO) is prepared (the former base being to the latter in the proportion 2 to 1); this liquid should have a specific gravity of about 1·35. Into this alkaline liquor sawdust is dropped, with constant stirring, till a thick paste has been formed. The mixture, placed upon iron trays in thin layers, is heated to a temperature not exceeding 200° C. (392° F.), until a sample is found to be wholly soluble in water. Further heating is still necessary, for although the cellulose and fibre of the wood have wholly disappeared, but little oxalate has yet been formed. By prolonged heating at the same temperature, the dry mass acquires such richness in sodium oxalate, as to yield about one quarter of its weight of crystallized oxalic acid ($C_2H_2O_4+2H_2O$). The sodium oxalate first formed remains undissolved, when the roasted mass is treated with a limited amount of cold water; and by subsequent conversion into a calcium salt and decomposition of that compound by dilute sulphuric acid, the sodium oxalate is made to yield oxalic acid itself. Sawdust gives nearly half its

weight of oxalic acid when submitted to the above treatment, while the alkalies used are almost wholly recovered for subsequent repetitions of the same operation. Oxalic acid is largely used in the preparation of other chemical products, in analytical chemistry, and in dyeing and calico printing. It is said that not less than 2 tons are the weekly produce of a single well-known chemical work, where the artificial process just described is carried on; it may be imagined that the tedious and costly old method for extracting this acid from docks, sorrel, and other plants, so long carried on in the Black Forest and similar localities, is giving way before the new process.

Carbolic acid, phenol or phenyl hydrate (C_6H_5HO), is a substance closely allied in chemical relationships and physical properties to the creasote of wood-tar. It is a powerful and useful deodorizer and disinfectant, especially when employed in conjunction with the fumes of burning sulphur (SO_2) or solutions of the sulphites, or these compounds in the solid form—lime, for instance, partly saturated with carbolic and partly with sulphurous acid. Carbolic acid is preventive of decay. Carbolic acid, though more nearly related to the alcohols than to the acids, may be readily dissolved from the mixture of neutral hydrocarbons with which it is associated in heavy coal-tar oil (its chief source) by means of a solution of an alkali, such as soda. In this way a sodium carbonate, soluble in water, is formed, while the other matters present remain undissolved, with the exception of small quantities of two other similar acids (creasote C_7H_8O, and phlorol $C_8H_{10}O$), traces of naphthalin,

&c. From its solution in soda the crude carbolic acid may be separated by the addition of sulphuric acid; and then by further treatment may at last be obtained as a white crystalline solid, fusing at 41° C., boiling at 186°, and dissolving in 24 parts of cold water. It may be rendered quite pure (for use in medicine and dentistry), by adding the purest commercial acid to such a quantity of cold water as is sufficient to dissolve the whole of it, filtering the solution, and then adding excess of common salt to it: the pure carbolic acid floating to the top is drawn off, distilled, and perfumed with a little geranium oil. It is stated that more than half the best carbolic acid of commerce is consumed in the preparation of certain coal-tar colours, as picric or carbazotic acid and coralline, and of the alkaline picrates used as fulminating and explosive powders. This picric acid just named was once made from indigo, then from the red resin of Xanthorrhea hastilis, but now it is chiefly prepared by the action of nitric acid upon a salt of sulpho-phenic acid, this latter compound being formed when carbolic acid is dissolved in oil of vitriol. Picric acid (C_6H_3, $3NO_2$, O) is a bright yellow crystallized acid of a powerful bitter taste, and capable of dyeing animal fibres of a permanent yellow.

Amongst other organic acids, I may here just name a few of considerable importance in the arts. Such are: *benzoic*, from the resin benzoin, and also made from the hippuric acid of cow's urine; *hydrocyanic* or prussic acid; *pyrogallic* acid, obtained by heating nutgalls; *salicylic* acid, which may be made from the essential oil of winter-green, or from carbolic acid; with *gallic* and *tannic* acids, from the same source;

and *valerianic* acid, now made by the oxidation of the corresponding alcohol, known as amyl-alcohol, and occurring in potato spirit.

Of mineral or inorganic acids I have described on preceding pages only those which are manufactured on a scale of great magnitude, but several others are now applied to special uses in chemical processes or in medicine. Such are *boracic* and *chromic* acids, *arsenic* acid, *molybdic* acid, and *phosphoric* acid. These acids are prepared and sold, either in the solid state or in the form of solutions of known strength. They are likewise employed in the form of salts, of which the number is legion.

In order to give some idea of the multitude of chemical preparations which are now manufactured in Great Britain, I will arrange in alphabetical order a dozen or so of the most important amongst them, adding a word or two of comment on each item in my list.

Acetone (C_3H_6O), a by-product in the manufacture of wood vinegar, is at once related to acetic acid and wood spirit: it is a thin liquid of pungent, but not unpleasant etherial odour, and is a very useful solvent for the removal of grease, &c., from fabrics.

Alcohol.—Besides common alcohol and wood spirit, several other alcohols of the same series are produced in the fermentation of sugars from different sources: fusel oil is a mixture of three or more of such compounds. Some of these alcohols are used in the manufacture of artificial fruit-essences, those for instance of pear, cognac, pineapple, &c. These essences are generally the ethers of acids of the vinegar series, and are much used in the flavouring of British spirits, liqueurs, and of confectionery.

Anthracen. ($C_{14}H_{10}$) and *naphthalin* ($C_{10}H_8$) are solid hydrocarbons from coal tar, to which much attention has been paid lately, since a large range of colouring matters can be obtained from them by oxidation, &c. Anthracen is peculiarly interesting from this point of view, since *alizarin*, the natural red colouring substance of madder root (Turkey red), is already made from it in such quantity as to replace one-third or more of the quantity of the natural dye annually used.

Benzol (C_6H_6) and *toluol* (C_7H_8) are liquid hydrocarbons found in light coal naphtha. Mauve, magenta, and many other brilliant artificial colouring matters are derived from these hydrocarbons after they have been converted into nitro-compounds ($C_6H_5NO_2$ and $C_7H_7NO_2$), and then into bases ($C_6H_5H_2N$ and $C_7H_7H_2N$).

Carbon disulphide (CS_2), made by distilling sulphur over red-hot charcoal, is much used for extracting oils, fats, and paraffins from seeds, residues, &c. A very small quantity of this substance preserves corn seeds, &c., from the attacks of weevils.

Chloral (C_2HCl_3O) and chloral hydrate ($C_2HCl_3O\,H_2O$) are prepared by passing dry chlorine gas through absolute alcohol for many hours—the latter compound, which is solid, being obtained by combining water with the former, which is liquid. Chloral is an excellent sedative and soporific, and is now manufactured in immense quantities in Germany, though extensively used in this country, and at one time prepared here to some extent.

Chloroform ($CHCl_3$) is closely related to chloral. It is made by distilling alcohol, water, and bleaching

powder together. Its great value as an anæsthetic is well known. Sir J. Simpson, in his work on Acupressure, published in 1863, says, "In Great Britain there are various establishments for the manufacture of chloroform. I know of one—that of Messrs. Duncan, Flockhart, and Co., of Edinburgh—where every day as many as 4000 doses of chloroform are regularly made." From inquiries recently made of this firm I learn that they now (November, 1876) manufacture daily from 7500 to 8000 doses.

Ether ($[C_2H_5]_2O$), commonly called sulphuric ether, is prepared by the action of a limited quantity of sulphuric acid upon alcohol. Although its use for producing insensibility to pain has become quite secondary, through the introduction of chloroform and of nitrous oxide, yet ether is still much employed in medicine. Machines for producing ice and cooling worts have been devised, in which the cold obtained is due to the evaporation of ether; while the solvent power of this very volatile liquid has led to its use for extracting and purifying oils, essences, and active principles (such as alkaloids), from various vegetable products.

Glycerine (C_3H_5, H_3O_3), which I have already noticed in describing the manufacture of soap, is also a by-product in the purification of the fats used in the manufacture of candles. It is made in large quantity and of excellent quality in this country. Glycerine, treated with a mixture of nitric and sulphuric acids, yields nitro-glycerine, an explosive liquid of spec. grav. 1·6, the chief constituent of dynamite, and is itself extensively used in medicine and surgery, and for many purposes in other useful arts.

Although the enormous and ever-increasing extent of manufacturing chemistry shows its national importance, the space at my disposal and the scope of the present work prevent me from giving particulars concerning many of its valuable and interesting products, which I should have wished to notice. I should like to have referred to the element *iodine* (from seaweed) and its salts—51 tons of this element were produced in Great Britain, chiefly in Glasgow, in 1871; to *bromine*; to many curious and useful metallic compounds; to such a liquid as hydrogen peroxide (H_2O_2), used, among other purposes, for giving a golden hue to human hair; and to the various organic bases, or alkaloids, such as quinine, strychnine, &c. I cannot, however, refrain from saying a few words concerning a material which is produced yearly in vast and increasing quantities, and by which chemistry has conferred a very great benefit upon the important art of agriculture. The manufacture of *Superphosphate of Lime* dates back about thirty years, and is due to a suggestion of Liebig's. Now the quantities of this artificial manure made in Great Britain will hardly be credited. One manure company near London sends out annually more than 40,000 tons of superphosphate, or of mixed manures largely consisting of that substance. According to the 'Chemical Directory,' there are one hundred and twenty manufacturers of this manure in England and Scotland alone. I have been furnished with very exact information as to the condition of this important industry in Ireland through the kindness of Mr. J. Smithson, who informs me that Messrs. Goulding and Co., of Dublin and Cork, make

nearly 16,000 tons of chemical manure (the basis being superphosphate) annually, while five other Irish firms together turn out every year about 15,000 tons. As the manufacture of superphosphate involves the employment of an amount of sulphuric acid (of spec. grav. 1·5 to 1·7) nearly equal in weight to the phosphatic materials used, it will be seen that much oil of vitriol is consumed in the production of this manure. The London works before referred to make and consume about 20,000 tons annually of sulphuric acid for this purpose; while the Irish firms above mentioned make about 12,000 tons of acid (of spec. grav. 1·5) altogether. The phosphatic substances which form the basis of superphosphate are very numerous, but those most largely employed are bone-ash, coprolites, Carolina phosphate, different varieties of the mineral apatite, and phosphatic guanos from several localities. The percentage of tricalcic phosphate (true bone-earth), or its equivalent in other phosphates, present in these materials varies from 50 to 90 per cent. This tricalcic phosphate becomes converted into the monocalcic by the action of sulphuric acid; of the latter salt a good superphosphate should contain not less than 20 per cent., equal to 26·6 parts of bone-earth made soluble. Monocalcic phosphate soon becomes insoluble in contact with earth, but before this happens, it has diffused itself more widely and fertilized a greater mass of soil than even the most finely-ground tricalcic phosphate could have done. It is, moreover, in such a physical condition, even when reprecipitated in the soil, as to be readily assimilated by vegetation.

OILS AND CANDLES.

By W. Mattieu Williams, F.C.S., F.R.A.S.

The alchemists and the older chemists used the term oil to designate any liquid that flowed sluggishly, and presented a slight degree of tenacity or viscosity. Thus sulphuric acid was included among their oils, and bore the yet surviving name of "oil of vitriol," simply on account of its limited fluidity. The word oleaginous is still used in the same sense, and the popular idea of an oil remains nearly the same as that held by the alchemists.

The oils of the modern chemist include liquids that are not at all oleaginous in their mechanical properties, and many substances which in their ordinary state are solid. These oils resemble each other in the fact that they are mainly or wholly composed of carbon and hydrogen, and are consequently inflammable, burning with flames of varying degrees of brightness, and producing by their free and full combustion, i. e. by their complete combination with oxygen, water and carbonic acid. A liquid may be oleaginous in appearance, and even greasy to the touch, but is not included among the oils of modern chemists, unless it also has the above-stated chemical composition and properties.

The varieties of such oils are almost innumerable, as nearly every species of animal and every species of plant produces an oil having some specific peculiarity

of its own. Besides these, there are the so-called "mineral oils," which flow spontaneously from certain rocks, or are obtained by the distillation of coal, shale, asphalte, &c. As these are derived originally from vegetable and animal fossils, they would be more correctly called "fossil oils." Thus all oils are of organic origin; all are formed by the organic reduction or "unburning" of carbonic acid and water, and when burned or recombined with oxygen, they return to these compounds.

Compound bodies may be decomposed by the simple application of heat, without combustion or other disturbing chemical affinity, and this kind of decomposition is now called "dissociation." Thus water, or rather steam, when heated sufficiently, is resolved into its constituent elements, hydrogen and oxygen; oxides of metals are similarly reduced, and every other chemical compound that has been sufficiently tested yields to the dissevering energies of the great repulsive agent, though the temperature at which this occurs varies immensely. In the case of the oils, the temperature of dissociation may be above or below their boiling point.

In the first case, the oil may be converted into vapour, and distilled without decomposition; but when the temperature of dissociation is below the boiling point, it becomes decomposed, and more or less completely carbonized, if we attempt to vapourize it by boiling it under ordinary atmospheric pressure.

The customary classification of oils is based upon this difference. Those which decompose at a lower temperature than their boiling points are called "*fixed oils*;" those which may be boiled and vapourized without decomposition are called "*volatile oils*."

The fixed oils pass by insensible gradations from oils that are liquid at ordinary temperatures to the solid fats, this difference being simply due to the temperature of the melting point. If a fixed oil ordinarily liquid, such as olive or sperm oil, is sufficiently cooled, it becomes a solid fat; while if a solid fat, such as lard, is heated, it becomes a liquid oil.

The volatile oils are usually more limpid than the fixed. Many of them are as nearly related to the resins as the liquid fixed oils are to the solid fats, and their relationship is of a similar nature; hence a difficulty arises when we attempt to draw the line of classification separating the volatile oils from the resins, and from certain other solid and volatile hydrocarbons, such as paraffin, naphthalene, &c. The volatile oils are more or less aromatic, the aroma being usually that which is characteristic of the plant from which they are derived, but more intense or concentrated. Hence they were regarded by the old chemists as the subtle essence of the plant, and the name "essential oils" is still applied to them. The common practice of describing the volatile oils and essential oils as synonymous, is not, however, correct, as there are volatile oils which are not essential oils, such, for example, as petroleum and the "paraffin" oils.

To determine whether an oil is fixed or volatile, let a drop fall upon a piece of clean blotting paper, and heat the paper until it is slightly charred. If the oil disappears leaving no stain behind, it is all volatile; if a greasy spot remains, it is wholly or partially fixed.

Animal oils are for the most part fixed, only a small number of volatile animal oils being at present known,

such as civet, which is secreted by a gland near the anus of the civet cat; castoreum, similarly secreted by the beaver; the oil of ants, obtained as a residue when ants are distilled with water; and ambergris, an aromatic semi-resinous substance, of disputed origin, found on the coasts and floating on the sea in tropical climates, and also in the intestines of the sperm whale, and in some fishes. A few others are known, but have not been well studied. It is quite possible that further investigation may reveal many more, as the peculiar odour of many animals, like that of plants, is probably due to the vapour of a volatile oil or resin.

Most of the volatile oils at present known are of vegetable origin; they are hydrocarbons, or mixtures of hydrocarbons with complex compounds of carbon, hydrogen, and oxygen, or simply with small proportions of sulphur, nitrogen, or oxygen. Their vapour renders them more easily inflammable than the fixed oils; they dissolve freely in alcohol and ether, and very sparingly in water. Those containing sulphur usually have acrid and pungent properties, such as the oil of mustard, horseradish, garlic, &c. The nitrogen found in some of these oils is regarded as an impurity arising from the admixture of other vegetable matter.

Many volatile oils, when cooled sufficiently, separate into a solid and a liquid. The solid is resinous or camphor-like, and is called a *camphor* or a *stearoptene*, while the portion which remains liquid has been named an *elæoptene*. These solid and liquid constituents are sometimes described as chemically combined, and analogous to the fatty acids and the glycerine of fixed oils; but this I think is incorrect. All the volatile oils

act as solvents to the resins and camphors to which they are most nearly allied, and an ordinary or natural essential oil, capable of the separation above described, appears to be merely a solution of the stearoptene in its own elæoptene.

Essential oils are extracted from flowers and other parts of plants: first, by pressure (or expression); second, by solution and distillation; third, by maceration; fourth, by absorption.

Simple pressure is only efficient where a portion of the plant is very rich in oil, as orange-peel, &c.

Solution and distillation are usually combined, as direct distillation of the dry vegetable matter commonly produces charring and partial decomposition or alteration of the oil. The petals or other parts of the plant containing the oil may be immersed in water in the retort or still, or they may be laid upon a perforated false bottom above the level of the water. In the first case, the oil is dissolved or washed out, and the vapours of oil and water distilled over and condensed together; in the second, the oil is volatilized by the steam, and passes over to the condenser along with it. When the boiling point of the oil is high, salt is added to the water to raise its boiling point near to that of the oil, but in all cases it is found possible to distil oils at a lower temperature than their boiling points by diffusing their vapour through that of water. If the water which thus distils over carries with it more oil than it is capable of dissolving, the excess is separated by standing, and is taken off; but if the water is under-saturated, the distillate is returned to the still, and redistilled with

a fresh portion of the substance containing the oil, and this process of "cohobation" is repeated until the water is saturated or super-saturated.

Formerly the stills were heated by placing them directly over a fire, but the modern practice is to heat them by steam.

The less volatile essential oils and the camphors are extracted by solution in alcohol or ether, from which they are afterwards separated by evaporating the spirit.

The oil contained in many gum-resins, such as myrrh, &c., is but partially obtainable by distillation with water, on account of the gummy matter in which it is enveloped. Such gum-resins are pulverized and exhausted two, three, or more times in cold alcohol, in which they are allowed to remain for some time, and frequently agitated. They are then placed in an open retort, and kept for some weeks or months gently warmed till the greater part of the alcohol is evaporated. The impure residue is then covered with water and slowly distilled.

The petals of many of the sweetest flowers refuse to yield their concentrated perfume, either by distillation alone or with water, or by solution in alcohol or ether, but will give it up to oils or liquid fats by maceration, or soaking in them from twelve to forty-eight hours, or longer. Olive oil, beef suet, deer suet, and pure lard are used for this purpose, either alone or mixed in suitable proportions. The fat is strained from the spent flowers and then supplied with fresh flowers, and the maceration repeated ten or twelve times. The essential oil is separated by agitating the fatty oil with

highly-rectified alcohol. Pomades may be directly perfumed in this manner.

Absorption, or "enfleurage," is adopted for separating the most delicate of the perfumes. Cotton cloths soaked in olive oil are spread on frames of wire gauze, and the buds sprinkled on them, then piled on each other, and left for several hours or days, the oil being afterwards pressed from the cotton. Or a film of fat, about a quarter of an inch thick, is spread over the glass bottom of a shallow frame called a "*chassis*," and the buds sprinkled on these. The frames are piled, and left from twelve to seventy-two hours; and this is repeated until the fat is saturated.

These processes commonly produce a mixture of two or more oils with varying boiling points. The more volatile is usually a pure hydrocarbon, the other an oil containing oxygen, or a camphor. These may be separated by "fractional distillation," i.e. distilling first at a low and then at a higher temperature, according to the boiling points of the oil required.

These devices of the perfumer are now becoming somewhat antiquated, or but rarely practised, as modern chemistry enables us to make strange transformations among the hydrocarbons and other organic compounds, and thereby to obtain many sweet perfumes with comparative ease and cheapness from substances having originally very different—even very foul and abominable odours.

The following Table shows the specific gravity and boiling points of the hydrocarbons from some of the more important essential oils:

Source of Hydrocarbon.	Specific Gravity at 20° C.	Boiling Points.
		deg. Fahr.
Orange-peel	·8460	345
„ Florence	·8468	345
Cedrat	·8466	343
Lemon	·8468	343
Bergamot	·8466	347
„ Florence	·8464	349
Neroli	·8466	343
Petit grain	·8470	345
Carroway, Hamburg, 1st dist.	·8466	349
Dill	·8467	343
Cascarilla	·8467	341
Elder	·8468	341
Bay	·8508	340
Gaultheriline	·8510	334
Nutmeg	·8518	332
„ Penang	·8527	330
Carvene	·8530	330
Wormwood	·8565	320
Terebene	·8583	320
Anise	·8580	320
Mint	·8600	320
Peppermint	·8602	347
Lauret turpentine	·8618	320
Thyme	·8635	320
Turpentine, 1st	·8644	320
„ 2nd	·8555	320
„ 3rd	·8614	320
„ 4th	·8600	320
Eucalyptus Amygdalina	·8642	340
Myrtle	·8690	325
Parsley	·8732	320
Rosemary	·8805	325
Cloves	·9041	480
Rosewood	·9042	480
Cubebs	·9062	500
Calamus	·9180	500
Cascarilla	·9212	489
Patchouli	·9211	489
„ Penang	·9278	495
„ French	·9255	500
Colophene	·9321	599

Many of the volatile oils are colourless; others are yellow, reddish, or brown; and a few are green or blue. All have characteristic odours; some agreeable, others unpleasant, with a sharp burning aromatic taste. As already stated, they are not greasy like the fixed oils, but have the opposite effect on the skin, making it rough and brittle. Most of them when exposed to the air absorb oxygen, and are partially converted into acetic, benzoic, cinnamic, and other organic acids, and partially into resins, changing from colourless or blue to yellow or brown, while at the same time they become viscous and less odoriferous. Oils thus altered may, by distillation, be separated into pure oil, and a resinous residue. The absorption of oxygen by different oils varies very greatly both in quantity and rapidity, commencing slowly for the first few days, then increasing in rapidity till a maximum is reached, when it again diminishes, until at last, after some months, it becomes imperceptible.

These changes take place still more energetically when the oil is placed in contact with active oxidizing agents.

The fixed oils are divided into drying and non-drying, according to their behaviour when freely exposed to the air.

The non-drying or greasy oils when quite pure are not altered by simple contact with the atmosphere; but in their crude or partially purified condition ordinarily gain from 3 to 5 per cent. by exposure to the air; they thicken somewhat, turn rancid, and sufficiently acid to redden litmus. This alteration is due to small por-

tions of foreign vegetable or animal matter, which act as ferments, and thus effect decomposition.

The drying oils undergo important changes: when freely exposed to the air, they absorb oxygen, and increase in weight to the extent of 6 or 8 per cent. If spread out thinly over a large surface, they become converted into a peculiarly tough and yellowish varnish, the "medium" of ordinary oil paints.

These changes are not due to impurities, but depend upon the composition of the pure oil. The best linseed oil, which may be regarded as typical of drying oils, contains about 80 per cent. of a substance to which the name of "*linoleine*," or "*linoxine*," has been given. It differs considerably from stearine and palmitine, the solid constituents of the fatty oils, is more like a resin or gum-resin, and the film which it forms when dried resembles that of the varnishes made by dissolving resins and gum-resins, such as copal, mastic, &c., in spirit or oils. It has, however, many advantages over them, being more elastic, much tougher, and does not contract in drying. My own experiments indicate a slight expansion of the drying film, when linseed oil is used as a medium or as a varnish without any admixture of turpentine.

A varnish composed of a solid resin, or gum-resin, dissolved in a volatile liquid like turpentine or alcohol, must necessarily contract on drying, inasmuch as the bulk is diminished by the evaporation of the solvent. A pure drying oil, on the contrary, hardens by oxidation, and gains thereby quite as much, and possibly more, than it may lose by evaporation. This is very

important to the painter, as his medium, when the colour is laid on at all thickly, dries first upon its surface and gradually through. If this drying is accompanied with shrinkage, and the film is at all brittle, the drying of the inner portion draws the hardened surface together and cracks it, to the hopeless defacement of the painting. Such a cracking of varnish is quite familiar to all painters, and some fine pictures have been spoiled by artists mixing their colours in copal, mastic, or other varnish media, which however brilliant for a time, ultimately become covered with a network of cracks, unless the film is of the thinnest. If a linseed-oil medium is largely diluted with turpentine, the shrinkage due to the evaporation of this volatile oil will cause it to crack like the varnish above described. Some experiments that I made a few years ago on the properties of linseed oil led me to the conclusion, that the practice of diluting oil colours with turpentine is altogether vicious and mischievous. It is very tempting, no doubt, on account of its aid to rapid drying; but besides rendering the linoleine film liable to cracking, it weakens it altogether; for when the linseed oil is thus diluted, the quantity of linoleine in proportion to that of pigment is of course diminished, and the pigment being of itself composed of fine particles of dry solid matter, these particles on the drying of the paint are insufficiently enveloped and imperfectly bound together by the linoleine film, and thus the picture loses its brilliancy, and the colours become flat and dull, or even crumble, as the drying becomes complete. A coat of

varnish may afford a temporary remedy, or rather disguise, for this defect, but is a bad and fading substitute for sound and brilliant body in the colour-medium itself. At the recent exhibition of the collected works of Landseer, I was painfully surprised at the fading of some of his finest works, which on their first exhibition at the Academy were so remarkable for their brilliancy, and I could not help contrasting these changes with the permanency of most of the works of the old masters. I suspect that turpentine is the chief delinquent, and have dwelt upon this matter, fully believing that it is very little understood by modern artists, and that it is of vital importance to the interests of pictorial art. It demands further and very careful investigation.

Besides the advantages derived from the toughness, elasticity, and non-shrinkage of the linoleine film, its usefulness is increased by its remarkable insolubility. I have carefully tested this, and find that it resists alcohol, turpentine, the fatty oils, wood naphtha, petroleum spirit, mineral naphtha, benzole, and even bisulphide of carbon, applied either hot or cold. Thus, if a picture is painted in a pure linseed-oil medium, it is possible to remove the varnish by either of these solvents without injury to the painting, and also to clean the picture with safety. The alkalis do act upon it; caustic potash and soda readily decomposing and softening it, while the alkaline carbonates do the same, but much more feebly. Even soap acts upon it slightly and slowly. The more turpentine is used in a paint, the more readily will soap remove it, so that frequent

cleaning of painted woodwork with soap and water may ultimately bring to light the original surface of the wood.

Now that the chemist has discovered the existence of this linoleine as the essentially useful principle of drying oils, and demonstrated its properties, the problem of commercially separating it for artistic uses is fairly presented, and should be solved. Pure linoleine should be obtainable in the liquid state, and nearly or quite colourless. A conscientious artist who desires his pictures to be permanent, would pay almost any price for the perfect medium which this would afford. It would combine all the desiderata of brilliancy, neutrality, smoothness, toughness, elasticity, and unfading permanency, with rapid drying and facility of working.

In the ordinary "boiled oil" of commerce we have a rude approximation to this desirable separation of linoleine. It is prepared by boiling linseed oil for several hours with litharge, raising the temperature just to the point of incipient dissociation, as shown by fuming and the formation of a top scum, and by the carbonization of a feather which is dipped in the oil as a test. A heavy sediment falls to the bottom, and the clear oil is decanted or filtered from this. I am not aware that the chemistry of the changes thereby effected has been properly studied, but suppose that it consists mainly in separating oleic or other fatty acid from the oil by combination with the litharge, to form an insoluble lead soap; and further, by the partial or total decomposition and evaporation of the gly-

cerine. If this explanation is correct, the decanted boiled oil must be crude or impure liquid linoleine, coloured by the carbonization of the decomposed glycerine, &c.

Magnesia, lime, oxide of zinc, oxide of manganese, and other oxides, capable of forming insoluble soaps, may be used instead of litharge.

The following is a list of the most important of the drying oils, of which the first five are best known as practically useful. Most of the others are very imperfect dryers, and contain more or less of non-drying, fatty glycerides, from which even linseed oil is not quite free. Their sources and specific gravities are added:

DRYING OILS.

Name of Oil.	Plant which yields it.	Specific Gravity.
Linseed oil	Linum usitatissimum ..	0·9351
Nut oil (walnut)	Juglans regia	0·9288
" (hazel)	Corylus avellana	0·9260
Poppy oil	Papaver somniferum ..	0·9270
Hemp-seed oil	Cannabis sativa	0·9307
Cucumber oil	Cucurbita pepo et melapepo.	0·9231
Oil of sunflower	Helianthus annuus et perennis.	0 9250
Tobacco-seed oil	Nicotiana tabacum et rustica.	0·9232
Grape-seed oil	Vitis vinifera	0·9202
Oil of julienne, or oil of honesty.	Hesperis matronalis ..	0·9232
Oil of camelina	Myagrum sativa	0·9252
Weld-seed oil	Reseda luteola	0·9358
Cress-seed oil	Lepidium sativum ..	0·9240
Oil of deadly nightshade	Atropa belladonna ..	0·9250
Oil of Madi	Madia sativa	0 9286
Oil of Scotch-fir seed ..	Pinus sylvestris	0 9312
Oil of silver-fir cones ..	Abies picea	0·9260

DRYING OILS—*continued.*

Name of Oil.	Plant which yields it.	Specific Gravity.
Oil of spruce fir	Abies excelsia	0·9283
Fatty oil of spruce fir ..	.. ..	0·9040
Cotton-seed oil *	Gossypium Barbadense ..	0·9306
Castor oil *	Ricinus communis	0·9639

* These two are sometimes classed with the non-drying oils, being very imperfect dryers.

The non-drying oils are of both animal and vegetable origin, and are of course very numerous, as the seeds or fruits of most plants contain more or less of oil, and all the higher animals have fat deposited in some of their tissues. The following list of fatty oils of vegetable origin, like the preceding list of drying oils, therefore includes only the more important of the oils that are commercially extracted and practically used :

NON-DRYING, OR GREASY VEGETABLE OILS.

Name of Oil.	Plant which yields it.	Specific Gravity.
Almond oil	Amygdalus communis ..	0·9184
Oil of beri	Guilandinæ mohringa.	
Apple-seed oil	Pyrus malus.	
Beech-nut oil	Fagus sylvatica	0·9250
Cacao butter	Theobroma cacao	0·8920
Oil from seed of	Butea frondosa	0·9170
" "	Calophyllum inophyllum	0·9420
" "	Canarium commune.	
Colza oil	Brassica campestris oleifera.	0·9136
Croton oil	Croton tiglium	0·9426
Oil of Cyper grass ..	Cyperus esculentus (root)	0·9180
Cocoanut oil	Cocos nucifera.	
Cherry-stone oil	Prunus cerastrus	0·9239
Cornel-berry-tree oil ..	Cornus sanguineæ.	
Oil of Daphne	Daphne mezereum ..	0·914 to 0·921

NON-DRYING OILS—*continued.*

Name of Oil.	Plant which yields it.	Specific Gravity.
Earth-nut oil	Arachis hypogæa	0·9180
Ergot oil	Secale cornutum	0·9220
Henbane-seed oil	Hyoscymus nigra	0·9130
Horse-chestnut oil ..	Æsculus hippocastanum	0·9150
Laurel oil	Laurus nobilis.	
Mesua oil	Mesua ferrea	0·9540
Black mustard oil ..	Sinapis nigra	0·9210
White mustard oil ..	Sinapis alba	0·9338
Oil from seed of	Nigella sativa	0·9200
Palm oil	Cocos butyracea vel avoira elais.	0·9680
Oil from root and seed of	Pinus quadrifolia	0·9350
Parsley oil	Petroselinum sativum ..	1·0780
Piney tallow	Vateria Indica	0·926
Plum-kernel oil	Prunus domestica	0·9127
Oil from seed of	Pongamia glabra	0·9150
Summer rape oil	Brassica præcox	0·9155
Winter rape oil	Brassica napus	0·9165
Oil of radish seed ..	Raphanus sativas oleifera	0·9187
Sesame oil	Sesamum orientale ..	0·9241
Spindle-tree oil	Euonymus Europæus ..	0·9571
Spurge oil	Euphorbia lathyris ..	0·9261
Oil from seed of	Sterculia fœtida	0·9230
Thea and camellia oils	.. ..	0·9270

To this list may be added: Oils made from the seeds of the cucumber, water-melon, pumpkin, bottle-gourd, squash, and other cucurbitaceous plants; the oil of beet-root, custard-apple, Avocado pear, bread nuts, telfaria, argania nuts, hickory nuts, pistachio, bean oil, buffalo-tree and lime-tree oils, maize oil, and a valuable but little-known oil obtained from the *wood* of some species of the *Dipterocarpus*, large trees growing in Cochin China, Chittagong, Pegu, the Malay Islands, and other countries on the extreme east of India. It is a resinous volatile oil, much used as a varnish in the countries where it is found, and it appears to be worthy of more attention than it has yet received in this country.

The mode of preparing the fixed vegetable oils, whether drying or greasy, is nearly the same in all cases. The fruit or seed is bruised or ground, and then subjected to strong pressure, by placing bags filled with the bruised mass between the plates of a powerful screw or hydraulic press. Steam heat is commonly applied, especially if the oil has a buttery or tallowing consistence at ordinary temperatures. The oil thus expressed is either filtered or allowed to clarify itself by subsidence, or impurities may be removed by agitation in boiling water and subsequent skimming off of the oil.

Another method of preparation is by boiling the bruised seed in water, and skimming the separated oil as it rises to the surface. Castor oil is thus prepared in the West Indies. Or the bruised seed, &c., is mixed with a small quantity of ether or alcohol (one-half to the whole weight of the mass), and after twenty-four hours' digestion, the mixture is pressed, and the ether or alcohol separated by careful evaporation. This method is only used for the preparation of the more expensive medicinal oils.

The crude oils thus obtained are more or less impure, and various means are adopted for refining or purifying them, such as violent agitation in boiling water, effected by forcing high-pressure steam from below through the mixture of oil and water, then clarifying by repose and filtration through coarsely powdered charcoal or charred bones. In other cases, when the crude oil contains foreign vegetable matter, it is agitated with one or two per cent. of strong sulphuric acid and left

for several days, when the oil becomes greenish, and deposits much tarry or carbonized vegetable matter. This and the free acid are washed out with steam and hot water or a weak alkaline solution, to neutralize the free acid and the oil is left to clarify by repose, or is filtered. Oils are also purified by means of chlorine, nascent oxygen, or hypochlorous acid, by exposing them to the action of a mixture of black oxide of manganese and hydrochloric acid, or black oxide of manganese and sulphuric acid, or a solution of bleaching powder (the so-called "chloride of lime") and sulphuric acid, and then filtering through charcoal. A strong solution of tan may be advantageously used in conjunction with the above (using the tan first if any of the acid processes are adopted) for the purpose of separating the gelatine as a solid precipitate of tannate of gelatine.

Chromic acid, which is a powerful oxidizing agent, is also used for the purification of oils. It is set free by adding to bichromate of potassa a sufficient quantity of sulphuric, nitric, or hydrochloric acid, to combine with the potassa. Simple filtration through *newly-burned* charcoal is sufficient for the purification of some crude oils, the organic impurities being oxidized by the gas which is condensed within the pores of the charcoal. Many other methods of purifying oils have been devised and patented, most of them based on the principle of oxidizing the impurities, and thus converting them into the state of charred solid particles that may be separated by filtration.

Rancid oil may be recovered by agitating it in boiling water, and treating it when cold with an alkaline solution just sufficient in strength and quality to neutralize the free acid without saponifying the oil. As magnesia is feebly alkaline, and does not readily combine with the fatty acids, it may be conveniently used for this purpose by simply mixing the rancid oil with a little water and magnesia, and boiling for about fifteen minutes.

Oils that have been refined by any of these processes may still be dark in colour, and require bleaching in order to attain their full commercial value; and this may generally be effected by simple exposure to sunlight. For this purpose the oil is placed in large shallow tanks, placed under a glass roof like that of a greenhouse. Small quantities may be bleached by exposing glass bottles containing them to the sunlight, this bleaching occupying some days or weeks. Chlorine, which is so efficient as a general bleaching agent, has a tendency rather to darken than to bleach many oils. On this account the chlorine processes of refining are but rarely used, or if used at all, demand considerable skill and caution. Its activity is so great that it may promote the oxidation not merely of the impurities, but also of the oil itself. Some oils will bear the action of chlorine better than others, and, with skilful treatment, may be both refined and bleached by it. This is the case with palm and cocoa-nut oils. Chromic acid may in like manner be used both as a refining and bleaching agent.

The most important of the animal oils are:

Sperm oil and Spermaceti, derived from the cachalots or sperm whales, mainly from the species named *Catadon macrocephalus*, or *Physeter macrocephalus*. These differ from the whalebone whales in having teeth, and an enormous development of the upper part of the head, which is about as large as one-half of the body, and serves as a float to raise the nostril above the water, thus enabling the animal to breathe easily. In this are cavities containing a light oil, which is all liquid during the life of the animal, but which after death concretes into a granular yellow substance—crude spermaceti,—and exudes the permanently liquid sperm oil. The upper part of the head near the nostril, called "the case," contains the most solid spermaceti; the lower portion, or "junk," more of the sperm oil. These are also found in smaller quantities in other parts of the body. Sperm oil was formerly used to a large extent for lamps, but the extensive destruction of the whales has rendered it so scarce and expensive, that it is now almost entirely superseded by colza and mineral oils. It is still in demand for the lubrication of the spindles of cotton mills, for which purpose it is superior to any other oil that can be procured. In like manner, spermaceti candles are almost entirely superseded by paraffin candles, except in hot climates and for photometric purposes, for which the standard spermaceti candle is still used.

Train oil, or common whale oil, is obtained from the blubber of the *balenidæ*, or toothless whales, of which there are many species. The blubber forms an

outer coating or envelope of the body, protecting these warm-blooded, air-breathing animals from the rigour of the Arctic seas. It is stripped from the carcass of the captured monster, packed in barrels, and brought home in a half-putrid state, and emptied into large wooden vats of many tons capacity. Here it is allowed to settle for some hours, after which the decomposing fat is run off into a copper boiler, and the separation of the crude oil is completed by the application of heat and subsequent pressure of the residue. In the more distant fisheries, such as those of the South Seas, the blubber is boiled down on board, and only the liquid oil brought home. The mountain of flesh forming the carcass of the animal is dropped into the sea and utterly wasted.

Quite a new development of the whale fishery has been recently effected in Arctic Norway, and judging from what I saw when there during the last summer, the Greenland whale fishery will find a powerful rival in that of Vadsö, in the Varanger Fjord. But a few weeks of the season had passed when I saw the thirty-seventh whale being peeled and cut up, and the thirty-eighth floated into the harbour on the same day. All these were captured and towed in by two small steam-packets, about as large as our common tug-boats.

On the bow of each of these vessels is a small swivel gun, from which is fired a compound projectile, a harpoon with hinged barbs, and a shell which explodes in the body of the whale, killing it almost instantly. A towing cable is then hooked to the nose

of the dead-floating monster, and he is tugged into the harbour of Vadsö, and hauled upon a huge inclined plane or slab of wood, where, in the midst of a stench that is indescribably loathsome, a number of gory workmen, armed with hatchets and scythe-like knives, and aided by a powerful winch, rip open the belly, wind out the stomach and intestines, cut away the whalebone, peel off the blubber, and finally hack the fleshy carcass into great slabs, which are afterwards dried and ground into a brown powder, now offered for sale under the name of "*waal-fisk-guano.*"

The bones and every other part of the animal are here utilized, and thus the valuable produce of each whale is greatly increased, and the prime cost of the oil proportionally diminished.

Train oil is obtained in smaller quantities from the blubber of other marine mammalia or cetaceans, such as the porpoise, dolphin, grampus, manatee, dugong, &c. *Seal oil* is similar, both in origin and properties.

Fish oil is obtained from the livers of codfish, hake, ling, turbot, and other fishes of the family *Gadidæ*, an also from some of the rays, such as the common skate, &c. The principal sources of supply are the Newfoundland and Loffodden cod fisheries. The bodies of the fish are split and salted, chiefly to supply the markets of southern Europe, where dried fish is in demand for fast-days, the oil from the livers being a secondary product. The livers are cast into large tubs or vats and exposed to the sun. As putrefaction proceeds, the oil is drained off and rudely separated. Thus pre-

pared, it is dark coloured, strong and nauseous, and is largely used in the dressing of leather.

Cod-liver oil, now so largely employed in medicine, is the same, but more carefully prepared by expressing the oil from *fresh* livers with the aid of gentle heat. When well made, it may be obtained in nearly the same state as that in which it exists in the liver, viz. almost free from odour, flavour, or colour.

"*Medicine oil*" is the name by which the Norwegian fishermen distinguish it from the common oil for leather dressers.

Pilchard oil is also a secondary product obtained in the course of curing the fish for southern exportation. It drains from them when they are heaped or stacked, previous to barrelling.

Lard oil is obtained by pressing hog's lard, or it may be separated by alcohol, 100 parts of which dissolve 123 parts of oil. It is now extensively used as a lubricant for machinery.

Oil of hartshorn, *Dippels oil*, or *Oil of bones*, is a secondary product in the manufacture of bone-black. It is a fetid oil, chiefly used for the manufacture of lamp-black.

Neatsfoot oil is prepared by boiling tripe or the feet of cattle, and skimming the oil which rises to the surface of the water; it is used for softening leather and in cookery. *Marrow oil* closely resembles this.

Oil of eggs, prepared by heating, pressing, and digesting in alcohol the yolks of eggs, is still in high repute in some places as a cure for excoriations, sore nipples, &c. *Oil of earthworms*, *oil of scorpions*, *oil of adders*,

oil of beetles, *oil of silkworms*, and other similar preparations were once in repute for their supposed medicinal virtues, but are now obsolete.

Animal oils and fats are refined or purified by the same methods as already described for the purification of the greasy vegetable oils.

The foundation of our knowledge of the chemistry of the fatty or non-drying oils was laid by M. E. Chevreul. His 'Recherches Chimiques sur les Corps Gras d'origine animale,' published in a collected form in 1823, is quite a classical treatise on this subject, which may be profitably studied even at the present day. It is to the direct application of the laws revealed by these and subsequent researches of the pure philosophical chemists, that we are indebted for all the improvements in the modern manufacture of candles. Rushlights have become curiosities; snuffers, and greasy tallow candles are abolished, while the costly wax and spermaceti candles of our youthful recollection are superseded by elegant and brilliant composite and paraffin candles, as direct consequences of the technical applications of pure chemistry.

The fatty oils, whether solid or liquid, animal or vegetable, are, with one or two exceptions, neutral compounds of glycerine with substances to which the name of "fatty acids" has been applied. These acids are composed of carbon, hydrogen, and oxygen, united in varying proportions. Some are solid at ordinary temperatures, others liquid. The solids are pearly crystalline substances, smooth and unctuous to the touch, but not greasy, while all are fusible into oily liquids.

The following list includes most of the natural fatty acids with their fusing and boiling points and sources:

Acids.	Melting Point.	Boiling Point.	Whence obtained.	
	deg. Fahr.	degrees.		
Stearic	159	..	Most animal fats and butter.	
Palmitic ..	143·8	..	Palm oil, butter, beeswax, &c.	
Oleic	57	..	Non-drying oils.	
Butyric	below 0	314	Butter, fermentation of lactic acid, &c.	
Melissic	192	..	Beeswax.	
Cerotic	174	..	Beeswax.	
Arachidic ..	167	..	Butter, oil of ground nut.	
Myristic ..	129	..	Nutmeg butter, cocoanut oil, &c.	
Lauric	110	..	Cocoanut oil, berries of the bay tree.	
Rutic or Capric	86	..	Oil of rue by oxidation, butter, cocoanut oil.	
Pelargonic ..	..	500	Leaves of the geranium.	By oxidation of oleic acid with nitric acid.
Caprylic ..	59	457	Butter, cocoanut oil.	
Œnanthylic ..	below 0	298 (?)	Castor oil by distillation, &c.	
Caproic ..	..	392	Butter.	
Valeric or Phocenic	below 0	347	Valerian root, fish oils. Oxidation of fusel oil.	
Erucic	93	..	Mustard seed and rape seed.	
Doeglic	62	..	The dögling, a species of sperm whale.*	
Physetoleic ..	..	..	Sperm whale.	
Moringic ..	32	..	Oil of ben.	
Angelic	113	374	Angelica root.	

* The oil of the dögling contains no glycerine.

Glycerine is a viscous, colourless liquid, of sickly sweet taste, which mixes freely with water and alcohol in all proportions, and sparingly with ether. Its specific gravity is 1·28; it is uncrystallizable, but below 40° Fahr. it becomes gummy and almost solid. It attracts moisture from the air, becomes more limpid, and is slightly volatile at 212°; but if distilled alone at ordinary atmospheric pressure it is decomposed, and the pungent vapours of acrolein, especially irritating to the eyes, are disengaged. It may, however, be distilled in vacuo, or in a current of superheated steam. Glycerine is refined by thus distilling in steam. It is composed, like the fatty acids, of carbon, hydrogen, and oxygen, but the proportion of the latter is much larger than in the ordinary fatty acids. The importance of this difference will be explained in connection with the manufacture of candles.

Glycerine is abundantly produced as a secondary product in the manufacture of candles, and its consequent abundance has led to many industrial uses that were unknown twenty-five years ago. Most of these depend on its emollient properties and its maintenance of liquidity, due to its non-volatility and absorption of atmospheric moisture. Thus the modeller uses it to maintain the moisture of his clay, and the drying up of mustard is prevented by adding a little glycerine to the water in which it is mixed. Common ink becomes copying ink by the addition of a due proportion of glycerine; and it is also added to paper pulp to render the paper soft and pliable. Gas-meters are advantageously filled with a solution of glycerine, as it does not freeze in

winter nor evaporate in summer. Its applications for the softening of the skin are well known. Besides these and other similar uses, its flavour is made available in the sweetening of liqueurs, wine, beer, malt liquors, &c. Treated with a mixture of sulphuric and nitric acids, or with concentrated nitric acid, it forms the powerfully explosive nitro-glycerine from which dynamite, &c., are prepared.

Glycerine is separated from the fatty acids with which it is naturally combined in oils and fats:

1st. By presenting to the acid a more powerfully basic substance, i. e. a substance having stronger affinity for acids than the glycerine has. When this is done under suitable conditions, the fatty acid leaves the glycerine and unites with its more powerful rival to form a soap. Common soap is a compound of fatty acids with soda, and soft soap, of the same with potassa. These soaps, like their bases, the soda and potassa, are soluble in water, and thus when soaps are made by boiling fats or oils with a ley or solution of soda or potash, the glycerine is dissolved in the soap solution, and its sweetness is one of the old-fashioned tests by which the soap-boiler judges of the completion of his process. If the oil or fat is heated with dry lime, with oxide of lead (as in the preparation of diachylon), or with other basic and insoluble metallic oxide, the glycerine is separated as a liquid floating above the insoluble soap, from which it may be simply poured off, and afterwards separated from the small quantity of oxide with which it is usually contaminated. Glycerine was thus discovered by Scheele in making lead plaster.

2nd. The fatty acids may be separated from glycerine by an opposite process, i. e. presenting a stronger acid to combine with the glycerine or to decompose it, and thus leave the fatty acid uncombined. Sulphuric acid is used for this purpose in the manufacture of candles.

3rd. *Dissociation by Heat.*—As already stated, the oils may be decomposed by the simple application of heat. If exposed to a sufficiently high temperature they may be dissociated with their ultimate elements, carbon, oxygen, and hydrogen. A lower degree of heat resolves them into solid carbon, gaseous and liquid hydrocarbons, and water. Less heat than this converts them into acroleine and other curious compounds, too numerous to be here described. By skilfully applying a still lower degree of heat (about 320°, or a little below the melting point of lead) in conjunction with water confined under pressure or with superheated steam, animal and other fats, such as tallow, palm oil, &c., may be dissociated into glycerine and fatty acids. These decompositions are now elaborately effected on a magnificent scale in the modern manufacture of *candles.**

* I may add that there are some modern chemists who explain the facts above stated by more complex hypotheses, who deny the existence of glycerine and fatty acids in natural oils and fats, and regard them as products of decomposition and new combinations with water, &c. I purposely abstain from the discussion of such questions here, and from the use of any chemical formulæ, as they would tend to obscure rather than elucidate the subject. Chemical philosophy has suffered much agitation of late, and is consequently rather turbid at present. When the errors of overlearned molecular speculation are duly precipitated, its natural clearness and simplicity will doubtless reappear.

The simplest and most primitive form of candle is the rushlight, which satisfied our grandfathers and grandmothers, and the excellence and economy of which are so highly praised by the Rev. Gilbert White in his classic 'Natural History of Selborne.' He tells how the decayed labourers, old women, and children, "gathered and soaked and peeled the rushes;" that "the careful wife of an industrious Hampshire labourer obtains all her fat for nothing; for she saves the scummings of her bacon pot for this use; and if the grease abounds with salt, she causes the salt to precipitate to the bottom, by setting the scummings in a warm oven." Candles were thus home-made by dipping the strips of rush-pith into this unsophisticated fat.

The next step in the luxury of illumination was the tallow-dip, made of ox or mutton fat, or a mixture of both, the fat being prepared by simply heating it until the membranes, &c., in which it was enveloped, are sufficiently frizzled to contract into lumps and sink to the bottom, and form the *greaves* or *cracklings* used for feeding dogs, &c. The wicks, made of loosely twisted cotton yarn, are cut to length, and suspended by their upper loop on a frame formed of rows of sticks arranged gridiron fashion, each stick passing through the loops of several wicks. They are then dipped three times into a vat containing tallow just melted down to its fusing point, then left to drain for a short time over the vat, and afterwards placed on a rack to cool and harden. This is repeated a second, third, fourth, or more times, according to the thickness re-

quired, which is determined by weighing. Candle dipping is best carried on in cool cellars, or only during the cooler months of the year, or in the nights of summer.

Mould candles are made of the same material as the tallow-dip, but with some regard to appearances. They are cast in hollow cylinders of pewter, polished inside, down the axis of which the wick is stretched. A number of these, twelve or more, are fixed in a wooden frame, the upper part of which forms a trough into which the bottoms or open ends of the moulds are fitted. On filling this trough the tallow runs down into the moulds, the bottoms of which, corresponding to the top of the candle, are formed by a conical cup, holding one end of the wick. If the tallow were poured into such moulds when heated above its melting point, it would adhere to the sides, and the candles could not be withdrawn, but if poured just at the temperature at which consolidation commences, they leave the mould freely. This temperature, varying from 108° to 120° Fahr., is determined by the formation of a scum or solid film on the surface of the melted tallow. American ingenuity has considerably improved the old candle moulds. Instead of separately stringing a set of wicks for each batch or cast of candles, the wick is now made to pass through the mould and continue unbroken perpendicularly below it, down to the reel or ball of plaited cotton. When the candles are set a series of plungers are wound upwards by means of a rack and pinion; the candles are all simultaneously thrust out of their moulds bottom upwards,

and as they ascend they draw up the wick thread from below, and leave it in its proper place down the centre of the mould. The out-thrusted candles are then cut off, and the mould is ready for another pouring. These American moulds are now in general use.

If an attempt were made to cast wax candles in this manner it would fail, on account of the great shrinkage of wax in cooling. As the solidification of the wax would commence at the surface next to the mould, this shrinkage would show itself by a hollow or perforation down the middle of the candle. Wax candles are therefore made by suspending and stretching a number of wicks from a ring, and over a basin of melted wax. The workman pours the melted wax down the wick from a ladle, and continues this basting process until the required thickness is obtained. They are then rolled while hot upon a flat surface of hard wood or marble, kept constantly wet, and thus worked into true cylindrical form and smoothed on their surface. The large wax candles used in Catholic and Mohammedan churches are made by placing the wick, previously soaked in wax, upon a flat slab of wax, and then bending and rolling the wax upon it.

These methods are still generally adopted when *pure* wax candles are made. Recently Messrs. Reiss have constructed a machine by means of which the wax, just heated to a plastic degree of softness, is squeezed through a cylindrical spout, along the axis of which the wick is previously placed. The wax and wick are forced out together, and thus a continuous candle is made, which is afterwards cut into the required lengths.

Beeswax is the raw material from which ordinary candles have been and still are made. In its crude state, as well known, it is of a dirty yellow colour, and is bleached by rolling into sheets or ribbons, and exposing them to the sunlight on meadows or grass plots. The *surface* of the ribbon is thus whitened, after which it is remelted and again made into ribbons, in order to expose a fresh surface; and this is repeated until the bleaching is completed. About a month is occupied by this process. By means of chromic acid set free by the action of sulphuric acid upon bichromate of potash, the bleaching may be effected in a few hours.

Other kinds of wax are also used, such as Chinese wax, derived from an insect, the "*coccus ceriferus;*" Japanese wax, of vegetable origin; Carnauba wax, from Rio de Janeiro, which is also a vegetable wax, remarkable and especially valuable on account of its high fusion point; and several other varieties of vegetable wax derived, like the two last, from palms. Besides these may be named the greenish Myrica, or myrtle wax, obtained from the fruit of the *Myrica cerifera*, or Wax myrtle. It is used in America for candle making. Wax candles are superior to tallow candles, not merely in respect to hardness, elegance, and cleanliness, but also on account of the greater purity and brilliancy of their light.

Spermaceti, which has been already described, has long been used for candle making, and is highly prized on account of its elegant, pearly, translucent appearance and the purity of the light, being, in this

respect, even superior to wax. In its pure state it is unfit for candle making, as it assumes so decidedly crystalline a structure on cooling, and is rather brittle. This is corrected by mixing it with 5 to 10 per cent. of wax, the mixture being cast in moulds.

All the above-named candles are composed of natural materials, merely altered by art to the extent of simple purification or bleaching. So long as only these were used, candle making was one of the simplest of the mechanical arts. Lately, however, it has undergone a complete revolution, and has become an elaborately chemical manufacture. As an example of the development of this branch of industry since it has left the hands of the "decayed labourers, old women, and children," and "the careful wives of the Hampshire labourers," I may quote a curious calculation lately made in the office of Price's Candle Company. Taking the number of candles made at their works in one week and the time that each candle will burn, it was found that if a week's produce could have been delivered to King Solomon when he finished his temple, a candle might then have been lighted at the altar, followed by another before that was burned out; and if this had been continued night and day to the present time, there would still remain enough to burn one hundred years longer.

Tallow is composed of stearic, palmitic, and oleic acids, combined with glycerine, as already stated. These compounds are, respectively, *stearine*, *palmitine*, and *oleine*. By reference to the table of fatty acids, it will be seen that the melting point of oleic acid is

much lower than either stearic or palmitic, and oleine is similarly more fusible than stearine or palmitine, so much so that it is liquid in ordinary weather. The first step in the modern scientific manufacture of candles was based on this. By simply pressing the tallow, a considerable portion of the oleine was forced out in the liquid state, and the harder and drier compounds, stearine and palmitine, remained. In this manner the first "stearine candles" were made. The thin edge of chemical philosophy having thus penetrated the candle makers' trade, it rapidly proceeded farther. The question, "Which is the illuminating constituent, the fatty acid or the glycerine?" naturally presented itself, and the answer was easily found; for by simply casting a sample of each into a common fire, the vast difference in their inflammability at once becomes evident. A more careful and delicate examination shows also that stearic acid burns with a brighter and clearer flame than stearine, and so on with the other acids of the fats available to the candle maker. Such investigations established the conclusion that glycerine is damaging to the candle; that a perfect candle must be composed of fatty acids exclusively.

There is another fact which might have led the scientific candle maker to the same conclusion, though I suspect that it was overlooked, as I do not find it anywhere mentioned in connection with this subject. It is, that the wax and spermaceti candles, already so long famous for the purity and brilliancy of their light, are made of fatty materials, which both differ from other fats or oils in having no glycerine in their com-

...ion. Besides this, the far greater proportion of oxygen contained in glycerine indicates comparative incombustibility, as it is only that portion of the carbon and hydrogen not already combined with oxygen that is capable of combustion.

The desirability of removing the glycerine being established, the next question for consideration was the cost of doing it, and particularly how much loss of material would be incurred. The chemist answered this at once, by showing that stearine yields 95·7 per cent. of stearic acid; palmitine, 94·8 of palmitic acid; and oleine, 90·3 of oleic acid. The first two of these being the valuable materials of the candle maker, his mean loss is but 5 per cent. in removing the glycerine, a very small sacrifice compared with the improvement of quality.

Referring to the three methods for separating glycerine which have been already described, it will be seen that the materials which they demand are remarkably cheap. For the first, lime affords an effective base; sulphuric acid, common oil of vitriol, that can be made on the spot at three farthings or less per pound, is the best possible acid for the second process; while the third demands only very hot water or superheated steam.

The lime process, which was the first practically carried out, is conducted as follows: About 10 cwt. of tallow or palm oil is melted with about 140 gallons of water, and to these are gradually added about 100 gallons of milk of lime, containing a quantity of lime equal to 14 per cent. of the weight of tallow.

This mixture is continuously stirred and heated for six or eight hours, until an insoluble soap is formed by the union of the fatty acids with the lime. The glycerine, thus separated, remains dissolved in the yellowish liquor which stands above the soap, and this liquor is run off for the separation and purification of the glycerine.

The glycerine is thus removed, but its place is occupied by the lime, the candle maker having exchanged a fat for a lime soap. This is worthless for his purpose, but the fatty acids being very feeble, the lime readily goes over to any strong acid. Sulphuric acid effects this separation. It is diluted to the specific gravity of 1·086 (i.e. 30 per cent. acid) and poured on the lime soap, kept heated by steam and well stirred. (About $2\frac{3}{4}$ cwt. of acid is required for the 10 cwt. of tallow.) The sulphuric acid combining with the lime forms solid gypsum. As soon as this combination is completed, and the fatty acids set free, the agitation is stopped, the steam cut off, and the gypsum allowed to settle to the bottom of the melted fatty acids. These are run off to a tank lined with lead, and, while still kept melting, washed first with dilute sulphuric acid, and then repeatedly with water, to remove any remaining traces of lime and gypsum.

At this stage a mixture of stearic, palmitic, and oleic acids is obtained, the two first being solid at ordinary temperatures, while the oleic acid is liquid; and as its presence softens the whole mixture, it must be removed. This is effected by first cooling the melted mixture very slowly, and thus allowing the

solid acids to crystallize as completely as possible. The result is a solid slab consisting of crystals of stearic and margaric acid with liquid oleic acid adhering around and between them. This heterogeneous mass is broken up, and put into porous bags made of hemp or horsehair, and submitted to strong hydraulic pressure, by which means the oleic acid is made to ooze out through the pores of the bags and flow into a receptacle below. The pressure is first applied at a low temperature and gradually increased according to the degree of hardness desired, the limit of course being the incipient fusing, or the softening point, of the stearic and palmitic acids.

The oleic acid is used for soap making, for softening wool, and, with further preparation, for the dressing of leather.

The pressed stearic and palmitic acids are now further purified by again washing them while melted with sulphuric acid, and afterwards with water, and then keeping them melted till all the adhering water is driven off. White of eggs beaten into a froth in the proportion of about one or two eggs to 1 cwt. of fatty acids is sometimes added with the last washings of water and well stirred in at 212°. The albumen coagulates and envelops the impurities, with which it settles to the bottom, thus clarifying the whole.

De Milly, of Paris, has improved this, the old process of lime saponification, by combining it with the third of the methods above specified (page 124), viz. that of dissociation by hot water or steam. By placing his tallow and milk of lime in a strong steam boiler and

heating it by steam at a pressure of 150 lb. to the inch and a temperature of 356°, he can work with less than half the quantity of lime, and thereby reduce the quantity of sulphuric acid required, in the same proportion, besides separating the glycerine more rapidly. Thus modified and the pressure carried up to as much as 180 lb. to the square inch, this method is still extensively used on the continent under the name of the "Autoclave" process. I am told that the quantity of lime is now brought down as low as 1 or 2 per cent. The higher the pressure, and consequently attainable temperature of the liquid, the smaller is the proportion of lime required.

Although it had been long known that concentrated sulphuric acid decomposes neutral fats in the manner before described (page 124), it was not until 1841 that this method was industrially applied. One of the advantages of this process is that it is directly applicable to very impure fats and mixtures, such as kitchen stuff, slaughter-house refuse, the residues of tallow melting, and from the refining of fish and other oils. The concentrated sulphuric acid not only separates the glycerine, but at the same time carbonizes the foreign organic matter mixed with the fats. The grosser impurities are first removed by subsidence from the melted fat, which is afterwards run into a strong iron boiler lined with lead and fitted with steam jacket and agitators. Strong sulphuric acid (sp. gr. 1·8) is added in quantities varying from 3 to 6 per cent. according to the degree of impurity of the fat. The vessel is then heated to about 300° or 350° by means of

superheated steam supplied to the steam jacket, when the fat foams, becomes brown, and evolves sulphurous acid, in consequence of the action of the sulphuric acid upon the impurities as well as upon the glycerine. Thus the fat is converted into a mixture of sulpho-fatty acids and sulpho-glyceric acid or sulpho-glycerine. These compounds have now to be decomposed, and this is effected simply by submitting them to the action of a large quantity of water in tubs, wherein the contents are agitated and kept at about 212° by means of a jet of steam. The sulphuric acid leaves the fatty acids and the glycerine to unite with the water, and the fatty acids which float to the surface are then drawn off, partially clarified by subsidence, and finally distilled.

For the reasons before stated (page 98), they cannot be distilled by simple heating over a fire and in contact with the air, but by careful exclusion of air, regulation of temperature by superheated steam, and distillation in an atmosphere of steam, they may be distilled without dissociation.* They are then bagged, pressed, and freed from water in the manner already described (page 133).

The application of the third method of separating the fatty acids, that of direct and simple dissociation by heat, is the latest development of the practical chemistry of candle making. The neutral fat is placed in large retorts, which are raised by direct furnace

* The distillation is now still further facilitated by the use of "vacuum pans" similar to those used in sugar-boiling, whereby the pressure of the atmosphere of steam is kept considerably below that of the external atmosphere.

heat to a temperature of about 570°, and superheated steam, at a temperature of 600°, is injected continuously amidst the molten fat for twenty-four to twenty-six hours; by this means the dissociation of the glycerine and fatty acids is gradually effected, and the separated products are also distilled over in an atmosphere of steam by the same operation. The success of this process mainly depends upon the skilful regulation of the heat. If the temperature is too high, the fatty acids and glycerine are further dissociated, and acroleine, gaseous hydrocarbons, and tarry residue are formed. If the heat is not sufficient, the separation of the glycerine proceeds too slowly, or is imperfectly effected.

When the dissociation and distillation are successfully completed, the fatty acids come over in sufficient purity for candle making, the separation of the oleine and adherent water being all that is necessary. The glycerine is purified by subsequent distillation. The elegant simplicity of this process naturally led to the expectation that it would supersede all the others. It was accordingly adopted at the Battersea works of Price's Candle Company, but has since been abandoned in favour of the sulphuric acid process. The chief reasons for this is, that in this country palm oil is largely mixed with the animal fats in candle making, and the natural colour of palm oil is yellow. The dissociation process leaves this colour unaltered, while sulphuric acid bleaches, at the same time that it separates the glycerine. The sulphuric acid affords the further advantage of refining dirty and otherwise im-

pure fats. If candles were made as of old simply from "P. Y. C." * tallow, the dissociation process would probably supersede all others; but in this country such tallow or mutton suet is in great demand for lubricating the heavy machinery (roll-necks, &c.) in iron works, and I fear I must add for the manufacture of very choice *fresh* butter. Rancid butter and salt butters are usually made from milk or cream. Tallow butter is not salted, and never becomes rancid, simply because the source of rancidity—butyric acid—is absent, and further because it is a refined or thoroughly purified fat, and such fat does not decompose, and therefore requires no salting. The idea that the cheapest and coarsest salt butters are the most adulterated is a mistake.

The stearic and palmitic acids in their pure state are liable to crystallization, especially when slowly solidified. Candles of such crystalline structure would be very brittle and unequally transparent. This defect was at first remedied by the addition of a small quantity of arsenious acid, and something like a panic resulted from the exaggerations of sensational newspaper writers, who described the deadly effects of breathing the arseniuretted hydrogen supposed to be given off by such candles. The arsenious acid was superseded by the addition of 2 to 6 per cent. of white wax, and by continually stirring the melted mixture until cooled down to a semi-fused pasty consistency and moulding while in this state. The

* This is the trade brand of the best tallow. "*Petersburg Yellow Candle.*"

modern practice is to add about 20 per cent. of paraffin to the fatty acids, which effectually checks their tendency to crystallize and improves their appearance and quality.

The fatty acids thus procured and prepared are moulded into candles in nearly the same manner as the tallow mould candles already described.

The candle wick, like the material of the candle itself, has been greatly altered and improved by the application of scientific knowledge to its manufacture. The snuffers and snuffer-tray are no longer included among the necessaries of household furnishing, and will shortly be found only in the collections of the antiquary. Comparing candlelight with gas-lighting, we may venture to claim for a candle wick that it performs the combined functions of the gas-works, the conveying pipes, and the burners. Oil gas has been made and used after the manner of coal gas, which it would certainly supersede but for the greater cost of the raw material. By simply dropping any kind of oil, or, better still, the separated fatty acids, upon a red-hot porous surface, such as heated coke or spongy iron, &c., it becomes converted into gas of far superior quality to that obtained from coal. If pure fatty acids are used, and the process properly conducted, their "destructive distillation" into inflammable gases is complete, and no solid residue is formed; but if common fats containing glycerine be used, or if gas is clumsily made, a carbonaceous residue is left upon the heated coke or iron of the retort.

In a candle, the heated upper part of the wick,

which is immersed in the flame, corresponds to the red-hot porous material of the oil-gas retort; the capillary attraction of the wick brings up a small quantity of fatty matter corresponding to the droppings of the oil retort; this is heated by the flame, and converted into the same gases as those produced in the oil-gas retort, with the advantage of being produced exactly on the spot where required for combustion.

By closely and sharply snuffing the wick of a common dip candle, and observing the top of the newly-snuffed wick, the bubbles may be seen rapidly forming and bursting to supply the gas which by burning on its outer surface forms the flame. Common tallow leaves a carbonaceous residue or coke on the wick, as it would in the oil-gas retort, but the pure fatty acids are completely converted into gas, and nothing is left behind but the ash of the wick itself. This difference appears to be but little understood, and I have not seen it explained in any treatise on the subject. It is, however, very important to the candle maker, as the absence of glycerine greatly simplifies his problem of producing a "self-snuffing" candle, a problem which has brought forth much ingenuity.

Formerly wicks were simply twisted, whereas now they are plaited in such a manner that in uncoiling they shall bend downwards or horizontally, and thus protrude their ends from the flame. With wax, spermaceti, or pure fatty acids this is sufficient, as the wick when exposed to the air burns to a simple white ash. When stearine candles were first made, De Milly,

1830, steeped the wicks in boracic or phosphoric acid, in order that a glassy bead might be formed at the end of the wick and drop off by its own weight. Phosphate of ammonia, sal-ammoniac, and other salts of ammonia are also used as pickles for wicks. A good wick must be free from loose threads or knots and of uniform thickness, as any irregularity produces guttering.

The introduction of paraffin candles is the latest and most important advance in this branch of industry. At the time of the Irish potato famine, a great sensation was produced by a Member of Parliament displaying to the House a white wax-like candle, which he affirmed had been made from Irish peat, and proposing to regenerate Ireland by the wealth thus obtainable from her bogs.

The project failed, for although such candles could be made, the cost of producing them exceeded their market value. Shortly after this (his patent is dated 1850) Mr. Young succeeded in obtaining both solid paraffin and liquid hydrocarbons, which he named "paraffin oils," by distilling Boghead coal (a very rich bituminous shale) at a lower temperature than is used in making coal gas. The same products were also obtained from Rangoon oil, a native petroleum, from other bituminous shales, from lignite, from cannel coal, from ozokerit (a wax-like mineral found in Galicia and Bohemia), from Trinidad pitch, and finally from the abundant oil wells of Pennsylvania and other parts of America.

The magnitude and importance which this branch

of industry has now assumed will be evident from the following figures, showing the importations of petroleum from America during the year 1875 :

	Refined Burning Oil.		Lubricating Oil.	Residuum.	Petroleum Spirit.	
	barrels.	cases.	brls. and casks.	barrels.	barrels.	cases.
London	169,762	3,250	2,511	1,000	53,173	—
Liverpool ..	95,853	2,830	300	29,358	30,913	—
Hull	20,226	8	—	—	—	—
Bristol	36,889	1,392	—	—	17,203	—
Clyde and Leith	4,233	4	535	9,387		—
Total ..	326,963	7,484	3,346	39,745	101,289	—

This amounts to about 17 millions of gallons. In 1874 it exceeded 20 millions of gallons, but the stock in hand at the end of 1874 was about 5 millions of gallons, and at the end of last year only 1½ million. This difference was mainly due to overtrading in 1874, which brought refined petroleum to the lowest price yet known in England, viz. 7¾d. per gallon, in December, 1874, and checked its subsequent importation.

The distillation of bituminous shales is still carried on in Scotland, at Bathgate and the neighbourhood, the shales used for the purpose being raised on the spot, and too poor and bulky for transport and gas making. The mineral oil works in the neighbourhood of Leeswood, in Flintshire, where for a short time the distillation of the rich "curly" cannel coal was so vigorously carried on, have nearly all collapsed, the American petroleum having reduced the price of the oils, &c., below the cost of producing them from a raw material, which has maintained a high price on account of its excellence for gas making. In Germany paraffin and paraffin oils are made from brown coal (lignite); but this industry has been seriously limited by the competition of American petroleum.

The process of manufacture is nearly the same,

whether shale, cannel, or lignite is used. The mineral is placed in retorts, generally of larger dimensions than those used for gas making, and raised to a low red heat. The outlet tube of the retort communicates with a simple form of condenser, cooled either by contact with water or by exposure of a large surface to the air. A current of steam passing through the retort greatly assists the distillation. At first, ammoniacal and water vapours come over, then brown vapours of the more volatile hydrocarbons, which continue with increasing density until the cannel, shale, or lignite is reduced to a dry coke. The "crude oil" thus obtained is a brown tarry liquid, floating on a considerable quantity of water in which the ammoniacal fumes are dissolved.

This is agitated, either directly or after a second distillation, with strong sulphuric acid, and then left for a short time for the "acid tar," or carbonaceous impurities held together by the acid, to settle and be removed.

Any acid that may remain in the oil thus treated is neutralized with soda, and the oil is now distilled fractionally, i. e. the first runnings of the more volatile hydrocarbons variously named "naphtha," "benzoline," "spirit," &c., are conducted to one tank, the next runnings of burning oil to a second vessel, and the later or "heavy oil" to a third. In some works these are all run together at first, and separated in a subsequent distillation, though, if necessary, they are again washed with acid and re-distilled. The liquids finally obtained are bright and clear. The most volatile, the "spirit," is colourless, the burning oil is straw-

coloured or of a greenish opalescent tint, and the heavy oil is yellow, and, according to temperature, contains more or less of crystalline scales.

The light oil or spirit is sold as "benzoline," and used chiefly for sponge lamps, or as a substitute for turpentine; the next or burning oil, after bleaching by exposure to sunlight in glass-covered shallow tanks, is used for the now well-known paraffin lamps; and the least volatile, or last running is separated into lubricating oil and solid paraffin, or "paraffin wax."

To effect this separation, the oil containing the crystalline scales is cooled nearly down to the freezing point, and for this purpose ice machines are used during the summer. It is then bagged and pressed, in order to separate the liquid from the solid paraffin.

The "*paraffin scale*" thus separated is of a yellowish or brownish tint, and requires further purification before it is fit for candle making. This is effected by washing it with the rectified "spirit," or first runnings, which dissolves the adherent liquid oil. It is then pressed again and the operation repeated if necessary, the paraffin for the best qualities being finally bleached and purified by washing when fused with sulphuric acid. An important improvement upon this process, has recently been introduced and patented, and is now in operation at the works of Price's Candle Company. The paraffin scale, simply pressed into flat cakes, is placed on shelves sloping forward, and heated for some hours nearly to melting. The oil gradually drains out, leaving the solid paraffin in a curiously spongy condition, and remarkably white and pure, with

a high melting point, due to the removal of the liquid and more fusible hydrocarbons. A portion of solid paraffin is also drained off. This is bagged, pressed into cakes, and again drained.

The advantages of this process are that it supersedes the expensive freezing apparatus, and also the washing with spirit, which is very dangerous in consequence of the inflammability of the spirit vapour. The drained spongy paraffin is subjected to the final bleaching and purification by sulphuric acid as usual. This process is due to an accident. A piece of pressed scale had fallen over a steam pipe, and remained exposed to about the temperature required. The foreman observed its purification and hardness, and suspecting that it was due to drainage away of the liquid, made some experiments, upon the results of which the improved process is based.

The solid paraffin thus obtained is a beautiful white pearly translucent substance, closely resembling spermaceti in appearance. Being a pure hydrocarbon, it burns with a brilliant pure white flame, provided it is supplied with sufficient air for complete combustion. It has, however, one serious defect as compared with spermaceti, wax, or stearic acid, viz. a lower melting point. This varies from about 110° to 150°, according to the mode of preparation and the material from which it is derived. Paraffin softens and becomes pliable at many degrees below its melting point, and thus candles made of this substance in its ordinary unmixed state are not suitable for warm climates, a fact demonstrated at a grand ball that was held in cele-

bration of the coronation of the unfortunate Emperor Maximilian at Mexico. An order for a large supply of candles for the occasion was sent to London, and duly executed by a merchant who was perfectly satisfied with the appearance and burning of the then newly introduced sample. But he knew nothing about fusion-points, and the paraffin candles went to Mexico. The grand *salon* was brilliantly lighted with them, and the dancing began as gaily as could be desired, but as it proceeded and the room grew warmer, the candles began to bow, then to bend and circle over more and more, to gutter and drop, and stream upon the guests. Dresses were spoiled, curses were muttered, and the festival became a fiasco, an ominous beginning of the short reign which terminated so tragically.

By more skilful preparation and by mixture with stearic acid, vegetable wax, &c., this defect of paraffin candles is now nearly overcome.

All the products above named as resulting from the distillation of shales, cannels, and lignites, are also obtainable from American petroleum, which, as it spouts or is pumped from the earth, is similar to the crude oil from the retorts, but is much lighter in colour, contains far less impurity, and is much more easily refined. The mode of refining is the same, but simplified, as the repeated washings and distillations are unnecessary. This, combined with the spontaneous supply of crude oil, has given the Americans an immense advantage over their British rivals, and it is only by great energy, economical management, and the skilful application of science in their works, that

the Scotch manufacturers have been able, even with their abundant supplies of shale, to continue the struggle against such odds. They would have entirely succumbed ere this, had not the skilful chemists attached to these works enabled their employers to convert their refuse or waste products into useful compounds, such, for example, as the sulphate of ammonia, now so largely produced by the union of the waste acid of the refineries with the ammoniacal vapours that pass over in the first stage of the distillation of the shale.

The paraffin obtained from ozokerit has a high melting point, and the burning oil is similarly dense. I have before me a sample of ozokerit burning oil manufactured by Messrs. Field, which has a specific gravity of 805° and igniting point of 160°. It burns beautifully in a common paraffin lamp. The quantities of ozokerit at present obtainable are too small to permit the expected development of its manufacture.

Before concluding, a few words are necessary on the subject of the supposed danger attending the use of petroleum and paraffin oils. Most pitiable nonsense has been printed, in daily and other newspapers, on this subject. These oils have been described as explosive, even as spontaneously explosive, and regarded as something akin to gunpowder or Greek fire. An explosive substance is one which, like gunpowder, guncotton, nitro-glycerine, &c., contains within itself the oxygen necessary for the combustion of its other combustible constituents, or which, like certain compounds of nitrogen, may be suddenly converted into gases by instantaneous dissociation. The mineral

hydrocarbons, whether derived from petroleum or by the distillation of shale, &c., have no such composition or properties, and are as perfectly inexplosive *in themselves* as water.

They are, however, like all other oils, inflammable, i. e. they may be made to burn if sufficiently heated and supplied with sufficient oxygen. Their vapour is an inflammable or combustible gas, and, like our common coal gas, it becomes truly explosive when mixed with certain proportions of air. Thus, if a mineral oil is heated sufficiently to convert it into vapour, and this vapour is mixed with air, we may obtain an explosion just as by allowing coal gas to escape. The temperature at which these oils are convertible into vapour varies greatly.

The "*spirit*" that first comes over in the fractional distillation is very volatile, and about as readily inflammable as turpentine. This, which is sold in the shops under the name of benzoline, should, like turpentine, be stored and handled with great care, as in hot weather its vapours if given off in a confined space may form an explosive atmosphere, or if a light is applied to the surface of such oil, it burns freely. The oil supplied for paraffin lamps is not so volatile; and, when properly prepared, does not give off dangerous inflammable vapours until heated to above 120°. Those who are uneasy about such oils should test them by simply pouring a little into a cup, and then plunging a lighted taper into the oil. They will find that, instead of the expected explosion or conflagration, the taper will be extinguished as in water.

The unpleasant odour supposed to accompany the use of mineral lamps is nearly as fictitious as the explosiveness. If the oil is spilled, of course its odour will be given off. If the wick of a paraffin lamp is turned so low as only to admit of imperfect combustion, a bad odour arises, but if properly managed (and no other lamp is so simple and manageable as a *flat-wicked* paraffin lamp) they burn without any odour whatever. In proof of this, I may state that I met a friend, who refused to use or try such lamps on account of their imaginary odour, at a conversazione of the Microscopical Society held in Somerset House. After admiring several objects, I asked him if he noticed any unpleasant smell. He answered, "No," and reiterated this answer when further pressed. I then told him to look around him. There were above four hundred paraffin lamps burning in this room where he smelt nothing, each microscope having its own lamp and that one a paraffin lamp. This source of light is so cheap, so clean, so convenient, and so brilliant, that unfounded prejudices against it are serious evils and should be refuted.

GAS AND LIGHTING.

By R. H. Patterson, F.S.S. (late Metropolitan Gas Referee).

The manufacturing of gas from coal for lighting purposes originated independently and almost contemporaneously in England and in France, in the closing years of the last century. The first maker of coal-gas in this country, who was seven years in advance of his French rival Lebon, was William Murdoch, a Scotchman, residing at Redruth in Cornwall, and employed in the management of mines in the neighbourhood. He manufactured coal-gas in iron retorts, conveyed it in pipes, and lighted with it his house and offices. He also employed the gas in a portable manner, to serve as a lamp in travelling to and from the mines by night. He made many experiments in the production of illuminating gas from various kinds of coal, wood, peat, and such-like substances; he saw the importance of purifying the gas, and certainly adopted the process of washing it with water, which is the cheapest if not the chief mode of purification still in use; and he also made and tried various kinds of burners, some in the form of jets and one similar to the Argand. In 1796, being then employed in Boulton and Watt's Soho Works at Birmingham, Murdoch proposed to James

Watt (son of the celebrated engineer) to employ gas as a substitute for lamps and candles, and to obtain a patent for the process. His proposal was not entertained; but two years afterwards he lighted part of the Soho foundry with gas; in 1802 he erected gas-works for the constant supply of the whole premises, and thereafter gas began slowly to come into use for the lighting of mills and other private establishments, including the Catholic College at Stonyhurst in Lancashire.

The proposal to employ gas for lighting streets and towns was at first received with ridicule, and met with most formidable opposition, and, as has since happened to not a few of our most valuable inventions, it was denounced as alike dangerous and impracticable by some of the eminent scientific authorities of the day. There was one man, however, who, on reading Lebon's Report to the French Institute, instantaneously recognized the magnitude of the invention; to use his own words, "the thought struck him like an electric shock;" and to this gentleman, Mr. Winsor, belongs the credit of giving wings to the invention, by the unflagging enthusiasm with which he supported it, and by the means which he took, though not always wisely or correctly, to attract to it the attention of the public. He at length succeeded, in 1810, in establishing the "Gaslight and Coke Company," now better known as the "Chartered Company," which, by means of recent amalgamations, is at present the largest Gas Company in London. The management of the works was at first entrusted to chemists, with the most disheartening

results, and the undertaking was on the brink of collapsing, when fortunately the Company called to their aid James Clegg, a pupil of Boulton and Watt (in whose establishment he became acquainted with Murdoch), who had applied himself to gas manufacture with great success. An able mechanician and a man of ingenious thought, he devised nearly all the essential appliances of gas manufacture at present in use; and his name, with that of George Low, who joined him as consulting engineer to the Chartered Company, still holds the foremost rank in the development of this great industry, as it was left by its inventor, William Murdoch.

Such was the beginning of gas making. Companies were rapidly established in all the large towns, some of the ordinary kind, some for supplying gas in a portable form, and others for making gas from oil. The Portable and Oil Gas Companies proved failures; and indeed Gas Companies of all kinds had little financial success for nearly twenty years after the establishment of the first undertaking. In those days inventions were not so rapidly matured by science as they are now, nor was the public so ready to adopt their practical application. At present, gas making is one of the most remunerative of industrial undertakings; and every little town or village in the kingdom is now lighted by it. So fully are the convenience and economy of this method of lighting recognized, that many of our large country mansions and isolated factories have small gasworks attached to them. In a portable form gas is now coming into use for the

lighting of railway carriages; and the advantage of using gas instead of oil in lighthouses is being gradually recognized. In fact, coal-gas is now the general source of artificial light—the only places in which it is tabooed being drawing-rooms and libraries, where its use is objectionable, owing to the bisulphide of carbon hitherto invariably and largely contained in it, but which it is now possible to remove.

It appears from a Parliamentary Report that upwards of seven million tons of coal are annually consumed in the gasworks and waterworks of the United Kingdom. London, inclusive of its suburbs, is lighted from nearly twenty gasworks, some of them of remarkable magnitude, especially the Beckton works of the Chartered Company, which are situated on the Thames at Barking. The coal annually consumed in these works exceeds two million tons; the gas rental of the metropolis is about 3,000,000*l.*, and the quantity of gas consumed amounts to about 14 million thousand feet a year. The gas rental of London increases at the rate of 10 per cent. per annum; and so fond are the public of light, and perhaps also so wasteful of it, that it appears from the Reports of the Chartered Company —who, having recently erected large new works, are able to supply gas under full pressure—that if an abundant supply of gas be provided, the consumption by the public increases largely without any appreciable addition to the number of the consumers.

Coal.—As gas is made from the volatile elements of coal, consisting of a combination of hydrogen gas with carbon vapour, bituminous coal is the kind most suit-

able for making it; anthracite, which is almost wholly carbon, is quite useless; and "steam-coal," in which the volatile elements are comparatively small, is also unsuitable, though in lesser degree. The bituminous or gas coals are identical in character with those used for household purposes, although some of them are too costly to be so employed. The Scotch cannel yields the largest quantity and richest quality of illuminating gas; the English cannel comes next; while the common gas-coal is supplied largely from Newcastle, and other parts of England and Scotland. The diversity in the gas-producing quality of these bituminous coals is very great. Taking the light-producing capacity of ordinary Newcastle coal as represented by 10, and of the best Durham at 15, Lesmahago cannel will be represented by 25, and Boghead by 40. The mode of stating the illuminating quality of gas is to say that it is of so many candle-power, i. e. that when consumed at the rate of five feet per hour in one of the best kind of burners, the gas gives a light equal to that of so many sperm candles, six to the pound.

Coal deteriorates as a gas making substance by exposure to the air. It ought, as far as possible, to be protected from rain: firstly, because when wet, especially if there be dross in the heap, it is liable to spontaneous combustion; and, secondly, when wet or damp coal is used in the retorts, more fuel is required in the furnaces, and the gas is somewhat deteriorated by the steam given off from the coals with it, which has to be condensed out of the gas in the process of purification.

It is advantageous, to pick out by hand from the coal the pyrites, or brassy veins or pieces, which are a compound of iron and sulphur—sulphur constituting the worst impurity in gas. This practice is now less in use in London than formerly, owing to the magnitude of some of the London gasworks, and consequently of the daily consumption of coal. Indeed the necessities of gas making are now so great, that frequently it cannot be ascertained whether the coal obtained is exactly the same as was contracted for; for, when a coal-steamer is waiting (say at Newcastle), if the coal owner has not enough from his own pits at hand to complete the cargo, he gets the required quantity from a neighbour, repaying him by-and-by in similar fashion.

Coal-gas.—When a house-fire is lighted in the ordinary manner, namely, at the bottom, dense smoke is given off by the heated mass of coal above. This is the vapour or fumes of the coal, which, when treated in the manner to be afterwards described, becomes Illuminating Gas. The smoke thus given off would, if burnt or properly consumed, yield both light and heat; but, under our wasteful system of grate fires, it goes off unconsumed, depositing its heavier elements as soot in the chimney, while the remainder passes as fouling matter into the atmosphere.

The method of gas making is very simple, and may be illustrated by the familiar juvenile experiment of filling the bowl of a clay tobacco pipe with pounded coal, closing the upper end of the bowl with clay, and placing the bowl in a fire; whereupon the gas imme-

diately issues from the stem of the pipe, and can be lighted. The retorts employed in gasworks are simply a larger apparatus of this kind. Coal is put into them,—the mouth-pieces are closed,—heat is applied, and the gas goes off like heavy smoke. In this form the gas is not permanent, and hence the necessity for the cooling and condensing apparatus whereby the crude gas is freed from its tarry condensable elements, which otherwise would not only impede the purifying processes, but speedily choke up the pipes through which the gas is supplied to the public.

The Retorts.—The retorts, or vessels in which the coal is distilled or "carbonized" (that is, reduced to solid carbon by the evolution of the volatile elements), were at first made of iron; and in small gasworks iron retorts are still used. But it was found that clay retorts are much better than iron ones, because they stand a higher heat and last longer. High temperatures are now considered preferable, on the principle of getting as much gas as possible from the coal in a short time, and thereafter selling the residual products. With low heats gas is obtained of greater purity and higher illuminating power, but much more tar is produced under this system of distillation, and consequently much less gas.

When retorts are required to be used intermittently (which is rarely the case) iron ones are better than clay, as iron suffers less than clay from the cooling down and heating again, and less time is requisite in putting iron retorts into action. In all large gasworks the retorts are usually 18 or 20 feet in length, open

at both ends—an arrangement whereby the retorts can be emptied of the coke, or spent coal, and also cleared from the carbon deposit formed in them, more readily and efficiently than if they had only one mouth.

Retorts are either round, oval, or ◠-shaped, the last-named being most in use. They are arranged in sets or benches, each bench containing sometimes as many as a dozen retorts, and each being heated by a separate furnace, or, where long retorts are used, by a furnace at either end, the flames and heated air from which are conveyed in flues all through the bench. As regards the shape of the retorts and also the number of them in each bench, the chief conditions to be observed are, firstly, that their shape, and the manner in which the heat is applied to them should be such that their contents (viz. the coal) shall be as nearly as possible exposed to the same degree of heat at every part, in order that the coal be distilled equally; otherwise some parts of the charge will be over-distilled before the gas is fully obtained from the remainder. The retorts which are most exposed to the heat of the furnace will wear out before the others; and, in this case, each of the damaged retorts must be thrown out of action, or else the entire bench must be taken to pieces and put in order again. Moreover, the retorts which are exposed to the greatest heat must be re-charged at shorter intervals than the others, or their contents will be over-distilled—the result being not only that gas of a low illuminating power is given off from the over-spent coal, but also that an additional amount of sulphur is driven off from the coke, dete-

riorating the purity of the gas and necessitating a larger extent of subsequent purification. It is usually reckoned that about one-half of the sulphur in coal is given off in the process of distillation in the retorts, the other half remaining in the residual coke; but the longer the coal is subjected to the heat of the furnace, the larger is the proportion of sulphur volatilized and mingled with the gas.

An incrustation of carbon forms in retorts, owing to a portion of the carbon vapours evolved from the coal being deposited in a solid form on the highly heated sides of the vessels. This incrustation (which has to be removed from time to time) not only lessens the heat-conducting power of the retorts, and thereby wastes some of the heat from the furnace, but it consists of illuminating elements of the gas, and is therefore to be avoided as much as possible. With this view, great attention is paid to the means by which the gas can be removed, or allowed to pass off, from the retorts as rapidly as possible. Usually there are two "ascension pipes" to each retort, one at each end, and these are placed outside the brickwork attached to the mouth-pieces, in order to keep them cool. The more *directly* the gas can be withdrawn, the better, without having to pass along the heated sides of the retorts, or over the heated coke in the latter stage of the distillation.

When the mouth-pieces of the retorts are opened, in order to withdraw the coke and to re-charge the retorts with fresh coal, it is necessary that the ascension pipes be closed; for otherwise there would either be a

back-flow of gas into the retorts, when it would be burnt and wasted, or, as is usually the case (i.e. where Exhausters are used), the air which rushes into the heated retorts would ascend the pipes and mingle with the gas. Even if common air were thus to mingle with the gas, it would seriously deteriorate its quality; but the air being acted upon by the heated coke, which thereupon ignites, forms carbonic oxide, with carbonic and sulphurous acids, &c., greatly adding to the impurities naturally produced in the distillation of coal-gas.

The closing of the ascension pipes during the recharging of the retorts may be effected, and at some gasworks (e.g. those of the Imperial Company at Fulham) is effected, by means of valves, which are shut when the mouth-pieces of the retorts are opened, and opened again when the mouth-pieces are closed and luted. But the simplest and almost universally used apparatus for attaining this object is the Hydraulic Main.

The Hydraulic Main.—By this apparatus the upper ends of the ascension pipes are made to bend and dip down into a trough containing water or tar, in such a manner that when the retorts are in action the gas (being evolved rapidly and in large quantity) easily bubbles through the liquid, but cannot return into the retorts, while at the same time the depth to which the pipes dip into the liquid in the trough is sufficient to prevent any air or products of combustion passing through it from the retorts, when these vessels are being recharged.

This trough, or large tube or pipe, is called the hydraulic main. It is at first filled to the required depth with water, into which the upper ends of the ascension pipes are made to bend or dip. The water is quickly converted into tar by the tarry vapours of the crude gas being condensed in it; and thereafter it remains constantly in the form of tar. An obstruction to the flow of gas through the "seal" of the hydraulic main occasionally takes place, owing to some of the tar being converted into pitch by the heat from the adjoining brickwork. This obstruction is more readily produced in proportion as the tar is kept longer in the hydraulic main; accordingly it is advantageous to promote the overflow of tar from the main, and Mr. G. Livesey recommends that the depth of tar below the dip pipes (i. e. the outlets of the ascension pipes), should be no greater than is necessary to permit of the gas bubbling freely through it.

Back Pressure.—When the gas from the retorts has passed through the "seal" of the hydraulic main (i. e. has bubbled through the tar) it enters on a new course, —namely, that of Purification. The crude gas has first to be freed from its non-permanent elements, which condense into tar, and which, if not thoroughly eliminated, would speedily choke the subsequent pipes; and secondly, it has to be purified from ammonia, sulphur, and carbonic acid. The vessels employed for this purification (viz. the scrubbers and purifiers) offer a considerable resistance to the passage of the gas, varying according to the different character of the purifying vessels, but usually being equal to that of from 20

to 30 inches of water. This is technically called the "back pressure," but the term is not a good one. The purifying vessels, it is needless to say, do not press the gas backward, as the term seems to imply; but they do not admit of the gas passing through them until it has previously acquired an adequate expansive or progressive force. The "back pressure" may be likened to the resistance offered by a dam to the onward movement of a stream, which is arrested and accumulates until it acquires weight or pressure sufficient to force its way through. Thus the gas, if not aided by special apparatus, must remain in the hydraulic main until by accumulation it acquires sufficient force to make its way through the purifying vessels. This difficulty must be overcome, for otherwise the gas would have to remain in the retorts until it has acquired a pressure or progressive force equal to that of 20 or 30 inches of water; whereas, as already stated, it is requisite that it should pass from the retorts as rapidly as it is generated, in order, *inter alia*, to avoid the deposit of a portion of its illuminating elements on the heated surface of those vessels.

The Exhausters.—To overcome this back pressure, and allow the gas to pass freely from the retorts, steam power is employed to work an apparatus called the Exhausters—which again is a bad term. It implies that it is necessary to use means to "exhaust" the gas from the retorts; whereas the gas being much lighter than the air, and also being evolved in large quantities from the coal, will naturally pass from the retort as rapidly as it is generated. The Exhausters

would be more correctly called Propellers: for their only use is, not to "exhaust" the gas from the retorts, but to impart to the gas, after it has left the retorts, a forward power or movement sufficient to make it overcome the resistance which it meets in the purifying vessels, and to enable it to pass through those vessels as rapidly as it is generated in the retorts. Accordingly the Exhausters must be worked with as much speed as will drive forward the gas with the same velocity as it issues from the retorts. And, as it is indispensable to maintain the hydraulic seal upon the retorts (in order that no air or foul fumes shall pass forward from the retorts during the process of re-charging), the exhausters are worked so as usually to leave a "seal" of about one half inch of tar upon the retorts, through which the gas bubbles freely when the retorts are in action, but which is sufficient to prevent the passage of air from them during re-charging. Accordingly, in the Exhauster house there is always a pressure-gauge before the eye of the workman, which shows him the depth of the seal in the hydraulic main; and he works the exhausters accordingly. Pressure-gauges are likewise kept at other places in the gasworks, and also thermometers, to show the back pressure and the temperature of the gas at the several stages of condensation and purification.

The Condensers.—The crude gas, as it leaves the hydraulic main, has usually a temperature of 120° to 130° Fahr., and is then passed through a series of pipes and vessels of various kinds for the purpose of cooling it, and thereby freeing it from the aqueous and

condensable tarry vapours. As it is advantageous to cool the gas gradually, on leaving the hydraulic main it is usually conducted through large pipes placed against the inner walls of the retort house, and sometimes also against the outer walls of the same building. It is then passed through cooling apparatus of various kinds—namely, a series of upright iron pipes in which it is exposed to the cooling action of the air; or pipes placed horizontally in a water tank; or "dry scrubbers," i. e. large upright iron cylinders filled with coke, bricks, or such-like material. By these means the tar is gradually separated from the gas, and is collected in tanks, from which in due course it is removed and sold as a commercial product. The discovery of the aniline dyes and other useful properties of coal-tar have made this commodity much more valuable than it used to be.

The chief condition to be observed in condensing is to cool the gas as gradually as possible without an inconveniently large apparatus of pipes and condensing vessels. It appears to be agreed that such a course tends to prevent or lessen the formation of naphthaline, which is a troublesome deposit of snowlike crystals that choke the pipes, and withdraws hydrocarbons from the gas. A *sudden* cooling is to be carefully avoided, as it tends to produce a deposit of naphthaline and diminishes the illuminating power of the gas; but if the cooling be done gradually, the temperature of the gas may be reduced to 60° or 40°—in short to any point practically desirable—without loss of illuminating power. A thorough cooling or condensing of

the gas is indispensable to the efficient action of the subsequent purifying vessels; and the temperature of the gas as it leaves the condensers ought not to exceed 60° Fahr.

The best method and apparatus for condensing the crude gas, after it leaves the large pipes placed along the walls of the retort house, is to conduct it through pipes placed in a water tank, through which a small stream of water is constantly flowing, the pipes being all on one level, and the gas being made to enter the pipes at the opposite end to where the water enters. By this arrangement the hot gas first meets the heated portion of the stream, and is gradually cooled as it approaches the other end of the tank where the cold water enters. One advantage of this water tank as a condenser is, that by increasing or diminishing the flow of water, the temperature of the gas can be properly regulated, whatever be the variations in the make of the gas or in the temperature of the atmosphere. In addition to the water tank, large vessels or chambers should be employed, of such size or diameter that in passing through them the velocity of the gas is greatly reduced, whereby the deposit of tar is promoted—in the same way as a rapid stream, when its motion is retarded in a pool, readily deposits the mud which would otherwise be carried on by the velocity of the current. A water tank of the above-mentioned kind might be employed in almost all gas-works, without any special supply of water; for the quantity of water daily required in gasworks would be sufficient, if it were first used in the condensing

tank. In the construction of such tanks, it is of the utmost importance that the pipes should be all on one level; for if they are arranged in several tiers, the gas will invariably pass through the upper tiers, where the water is hottest, and will shun the lower tiers, where the water is comparatively cold. And as the pipes must be sufficiently large or numerous to allow free passage to the maximum make of gas, it follows that if the pipes be arranged in tiers, the gas in the summer months, when the make is only one-third of what is required in winter, will pass entirely through the upper tiers, where the surrounding water may have a temperature of much more than 100°.

A process of condensing by means of pipes placed underground was recently tried at the new works of the Chartered Company, at Beckton; but it wholly failed; because, although a very great length of pipe was used, the soil prevented any appreciable radiation of heat from it. The ordinary condensers employed in gasworks are a series of upright iron pipes, sometimes annular in form (i.e. hollow, so as to increase the radiating surface). In practice these condensers appear to do their work tolerably well; but they are open to this objection, that they are subject to all the vicissitudes of the weather, sunshine and rain, which must obstruct the proper regulation of the temperature of the gas, notwithstanding that an apparatus is occasionally employed for making water drip over the surface of the pipes in hot weather.

Washers and Scrubbers.—Previous to the invention of gas making, ammonia was a comparatively scarce pro-

duct, and was chiefly obtained from camel dung, in Egypt. But it soon became evident that a large supply of ammonia could be obtained from coal-gas, and an apparatus was devised for this purpose of a very simple kind. Water is capable of absorbing about 770 times its own volume of ammonia-gas; and accordingly the coal-gas, after being condensed, was passed through vessels containing water. These vessels, called Washers, were at first of a very crude kind—merely tanks in which the water was kept in motion by revolving plates, and the gas was passed through in a tumultuous manner, in bubbles larger than a man's head. As this occasioned a great resistance to the passage of the gas, or, in technical phrase, produced a heavy back pressure, which was a serious objection, especially before exhausters came into use; and also as the gas made its way in large bubbles, only the exterior surface of which was acted upon by the water, this apparatus fell into disuse. Another method of absorbing the ammonia from coal-gas was by vessels in which the gas was made to ascend through a heavy shower of descending water. This form of washing is now rarely employed, partly from the fact, or belief, that a considerable portion of the hydro-carbons, or illuminating elements of coal-gas, were eliminated along with the ammonia when the gas was brought so roughly into contact with much water. To obviate these various objections, Scrubbers were adopted, and are now in general use. These are up-right iron cylinders, from 20 to 30 feet in height, usually filled with coke, while, from an apparatus at

the top, water is distributed equally, in fine spray or drops, over the mass of coke below. The gas, as it ascends through this moistened mass of coke, is brought gently in contact with the water, converting it into the ammoniacal solution called gas liquor, which is an article of commercial value, from which the ammonia is obtained by a very simple process in chemical works.

Another kind of scrubber, devised by Mr. G. Livesey, has recently come into use, in which, instead of coke, the vessel is fitted with thin deal boards, set in tiers perpendicularly, and slightly crossing each other, and at about one-third of an inch between each. The advantage of the Livesey scrubber is, that the space left for the passage of the gas is so large that no back pressure is occasioned; the scrubber is not liable to choke up like coke scrubbers; and though it is more costly in construction, it is exceedingly enduring, in consequence of the tar in the gas acting as an antiseptic, preserving the wood from rotting or decay.

It is not improbable, however, that owing to the improvements recently made in the form of washers, especially by Mr. G. Anderson, these vessels will again come into use, and prove more efficient than even the best kind of scrubbers. In Mr. Anderson's Washers, a series of metal plates, with toothed edges on the bottom, are placed so as just to dip into the water, in such manner that the gas does not encounter much resistance, and passes through the water, under each of the plates, in small-sized bubbles. He is now introducing a new apparatus for the same purposes, which, alike for efficiency, convenience in purifica-

tion, and also economy of space, leaves nothing to be desired.

The Apparatus, as here shown, consists chiefly of a series of Washers placed one above another, in each of which Washers (or separate compartments) there is a revolving drum fringed with a brush of whalebone, or such-like material, which at each revolution dips into the water in the lower part of the compartment. In the upper half of the compartment the gas passes through the wetted brush, which revolves in the opposite direction to the movement of the gas.

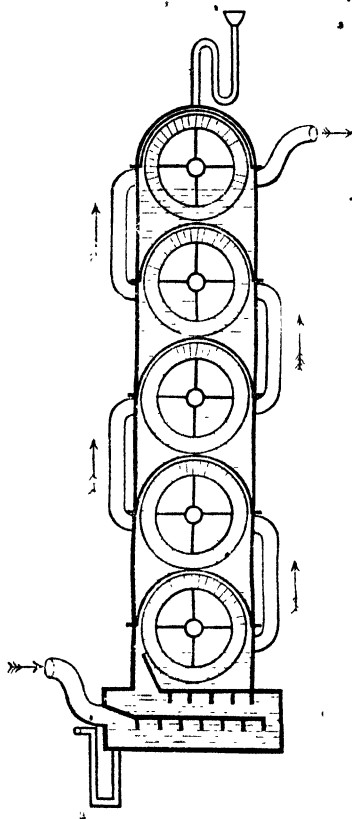


FIG. 1.—ANDERSON'S NEW WASHER (shown in Section).

Like the separation of the tar from the gas, but to a much greater degree, this purification from ammonia is a profitable course for gas companies—in this respect differing from the other purify-

ing process to be afterwards described. For example, at the Blackfriars Gasworks, where Mr. Mann's scrubber was in use, the outlay and profits were as follows: There were five scrubbers, costing 500*l.* or 600*l.* each, or less than 3000*l.* in all; but the value of the ammoniacal products obtained from these scrubbers was 3000*l.* per annum; while the cost of labour per annum was next to nothing, the scrubbers being self-acting, and the coke with which they are filled requiring to be changed (at the cost of about 10*l.* for each scrubber) only once in two or three years. Hence the cost of construction was in this instance repaid in a single year, and thereafter a large annual revenue is received from these vessels.

Ammonia, although in itself an agreeable substance, constituting the pleasant stimulant of smelling salts, is an impurity in coal-gas, in the sense of being a nuisance to the gas consumer; for when burnt along with the gas it loses its character as ammonia, and is resolved into its elements (namely, one volume of nitrogen, and three volumes of hydrogen), which, uniting with the oxygen of the atmosphere, forms nitrous acid and watery vapour. The nitrous acid, which tends to become nitric acid, by continued oxidation by the atmosphere, acts most injuriously upon metal fittings and ornaments, especially upon bronze, brass, &c.

The Purifiers.—These vessels are especially designed for the purpose of purifying the gas from sulphur, or from sulphur and carbonic acid. Carbonic acid deteriorates the illuminating power of gas, but it does not

occasion any nuisance to gas consumers. The sulphur in coal-gas, however, constitutes a most objectionable impurity, not only from its causing a bad smell (and leakages of gas not infrequently occur in houses), but from the production of sulphurous and sulphuric acid when the gas is burnt. It was at one time strenuously maintained, especially by Mr. L. Thompson, that no sulphuric acid is formed by the combustion of coal-gas containing sulphur; but this is quite erroneous: indeed, on testing the white film or incrustation formed in the cylinder of an Argand burner, I have frequently found the presence of sulphuric acid. The evidence of Dr. Letheby, supported by general experience, shows that apart from the fouling of the air of rooms where gas is used, the sulphur-acids produced by its combustion damage the binding of books and many articles of furniture to a serious extent. Indeed, it is the presence of sulphur in it which constitutes the greatest objection to the use of gas, and which in many cases has hitherto excluded it from drawing and dining rooms, or in some houses altogether.

The material first employed in Purifiers was lime, which is capable of absorbing both the sulphuretted hydrogen and the carbonic acid contained in coal-gas. But lime is costly, dirty in the gasworks themselves, and occasions such a nuisance to the neighbourhood, in the shape of sulphuretted lime, that its employment in purification is objected to in the urban districts of London, and is being more and more objected to in all large towns. Oxide of iron is

a perfect absorbent of sulphuretted hydrogen, and occasions no nuisance as compared with lime; and some twenty years ago, Mr. F. Hills found that it could be revivified simply by the action of the atmosphere; so that, although a more costly material than lime, it was much cheaper to use, as it could be employed over and over again in the purifiers, and thereafter sold as an article of commercial value. A long and costly lawsuit ensued between Mr. Hills and the Chartered Company, who denied his patent rights, but the decision of the Court fully established Mr. Hills' claim to this invention. The mode of using oxide of iron is as follows: As soon as it has become so saturated with sulphuretted hydrogen as no longer to purify the gas adequately, the material is taken out of the purifiers, and exposed to the air; when, being acted upon by the oxygen in the air, it reverts to its original condition, while the sulphuretted hydrogen which it had absorbed is released from the iron, and remains in the material as free sulphur in the form of a fine powder. In this manner the oxide of iron is employed over and over again in the purifiers, until the sulphur accumulates in it to the extent of 40 or 50 per cent., and it is then sold to the chemical works, where the sulphur is obtained from it by roasting, and the desulphuretted oxide of iron is ready to be used again as fresh material in the gasworks. This invention, however, is now seen to have had one very detrimental effect—namely, that, as oxide of iron has no power to absorb carbonic acid, the greater part of

this substance was left in the gas, thereby seriously reducing the illuminating power.

Lime is used in purifiers on a series of trays, and in layers seldom exceeding 6 inches in depth. Oxide of iron, which offers less resistance to the passage of the gas, is used in a similar manner, but in layers of 18 or 24 inches deep.

By far the larger portion of the sulphur in coal-gas exists in the form of sulphuretted hydrogen; and, as already said, can be so easily removed that it has for long been totally prohibited in this form under penalty. But the sulphur impurity exists in other forms, chiefly, if not entirely, as bisulphide of carbon, the most stinking of all coal-gas elements. Dr. Letheby, as the sanitary officer for the City of London, and the gas examiner for the Corporation, was the first to call public attention to the noxious character of this impurity; and in the London Gas Act of 1860 it was enacted, that any company whose gas contained more than 20 grains of sulphur in this form, should be liable to heavy penalties. Nevertheless, as no reliable or adequate method was known of purifying it from this impurity, these penalties were not put in force. Indeed, even at the new works of the Chartered Company, at Beckton, where the purifying apparatus is on the largest scale, and where lime has been used in unusual amount, the failure of the sulphur purification was so great, that the gas manufactured at these works contained nearly 40 per cent. more sulphur than was the case at the old and abandoned works of the same company.

In the beginning of 1872 I devised a method of employing lime purifiers on a new principle, whereby the contents of any required number of these vessels can be converted by the action of the gas itself into pure sulphide of calcium, and thereafter maintained in this condition as long as may be desired; and it has since been demonstrated on a practical scale, that this process is perfectly adequate to purify coal-gas from bisulphide of carbon. I have also applied the same principle and processes for the systematic production of other alkaline sulphides in gasworks by the action of the gas itself, and also to the employment of alkaline vessels in such manner as to purify the gas from its impurities, viz. carbonic acid, sulphuretted hydrogen, and bisulphide of carbon. When these processes are generally adopted, a long-existing difficulty will be at an end, and the objections to the use of gas in well-furnished rooms will at length be removed. By some of these processes the whole work of purification is performed in closed vessels, thereby preventing nuisance, which is so objectionable in urban districts; and by one of them, I employ one gas impurity (Ammonia) in such manner as to eleminate all the others (viz. CO_2, SH_2, and CS_2) while being itself removed.

Gasholders are also called gasometers, but as the metering of the gas is a subsidiary matter, it is better to call them Gasholders. A gasholder consists of two parts: the water tank and the holder. The Tank is an excavation in the ground, lined at the sides and

bottom with strong water-tight masonry or concrete, and filled with water. The Holder is a large circular vessel framed with plates of sheet iron, like an inverted tumbler, and supported by iron pillars, with pulleys to allow the free rising and sinking of the vessel. The holder, which is a little less in diameter than the tank, is immersed in the water so far, that when the lower rim of the holder reaches the bottom, a clear space is left between the top of the holder and the surface of the water. The gas is then admitted by a pipe, the outlet of which is above the surface of the water; and as the gas enters, the holder rises until it is wholly filled with gas. The apparatus may be familiarly explained thus: Take two straight-sided tumblers, one of which, being a little smaller in diameter, when inverted, fits into and descends to the bottom of the other, or lower one, which is nearly filled with water: a tube rising through the bottom of the lower tumbler up to the surface of the water admits the gas, which fills and raises the upper tumbler —care being taken that the lower rim of the upper tumbler always remains in the water, thus preventing the gas from escaping, in technical language "sealing" the holder.

Sometimes gasholders are made in the "telescopic" form, or "double-lift," to save space and also the cost of a tank. So made, when the first lift (the common single holder) is filled with gas, the second lift, or additional holder, fills and rises in like manner. The lower rim of the second lift is sealed in the water,

like the first one, but in a much cheaper manner, which may be figured thus:

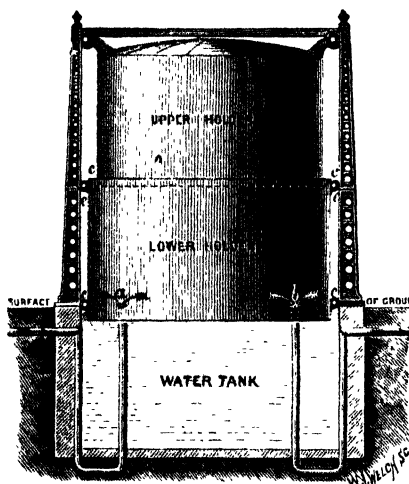


FIG. 2. *a*, Inlet; *b*, Outlet; *cccc*, Water-Seals.

The sides of the holder consist of several tiers of metal plates of uniform height, say 3 feet; and upon each is marked the cubical space which it represents in the holder, in 1000 feet of gas, so that at a glance the quantity of gas is at once seen. The holder is also weighted in such manner as to impart to the issuing gas the amount of pressure requisite to give the proper supply to the public. Gas in pipes readily ascends to any height without pressure being imparted to it; but if any part of the district supplied is below the level of the gasworks, pressure from the holders is

required at the rate of an inch for every 100 feet of lower level.

The Meter.—On issuing from the Holders, all the gas is passed through the Meter-house, where the amount of the supply is measured and registered.

It is usual to have in the meter-house a Lowe's jet photometer constantly burning, in order to show at all times the illuminating power of the gas. The principle of the apparatus is this, that, when gas is consumed in a jet burner, under an invariable rate of pressure, the length or height of the flame will correctly indicate the variations in the illuminating power of the gas.

To produce gas of the illuminating power required in London, namely, 16-candle gas, from 3 to 8 per cent. of cannel coal had to be used in the retorts along with the common Newcastle coal,—but now it is found that cannel coal can be dispensed with, provided the gas be thoroughly purified from the carbonic acid, 1 per cent. of which reduces the illuminating power of gas by at least 7 per cent. When a fog occurs, whereby the consumption of gas light by the public is suddenly and largely increased, cannel coal has to be used in unusual quantity, in order to increase both the quantity of the gas and also its illuminating power, whereby the same quantity of gas goes farther. By this means, without increasing the number of retorts in action (which it is impossible to do on the instant), the companies are enabled to meet the extra demand for light when suddenly arising. As the cost of an ordinary-sized gasholder is 25,000*l.*, the storage of gas is an expensive

process; and moreover many of the London gasworks have no space for the construction of additional gas-holders; so that in some cases the storage does not amount to twelve hours' supply, and in none of the works of the London companies, even those out of town, does the storage of gas exceed a single day's supply. At the same time, any sudden increase in the make of gas is impossible; because, even when there are retorts in reserve, it takes about three days' time to properly heat up to the proper temperature a bench of retorts which has been lying idle. Accordingly, it is only by means of an increased use of cannel coal in the retorts, that the companies can meet any sudden demand upon them for more gas light.

Proposed Processes and Improvements in Gas Making.—Gas making is so extensive and so profitable an industry, that the patents taken out in connection with it are well nigh innumerable. The remarkable rise in the price of coal, and the serious strike of the gas stokers in London, recently gave a special impetus to such inventions. The most important of these proposed new processes have been devised with a view to find other means of making gas than from coal, and relate to the employment of oils in various manners, either as entire substitutes for coal, or as auxiliaries. In both cases the inventors adopt what is known as the "carburetting" system (which might be better termed "carbonating"), whereby either air or poor gas is passed through vessels containing naphtha, petroleum, or such like substances, the rich carbon vapours from which mix with the air or gas passed through them, yielding

a high illuminating power. The principle of all these inventions has long been known and frequently tried practically, the only difference being in the details of the several processes.

Oil-gas companies were formed at a very early period in the history of gas manufacture; and at first this method of producing light found great favour, and seemed likely to prove a formidable competitor to coal-gas. But one by one these companies collapsed: the most notable case being at Bath, which town was fully lighted by oil-gas, but it entirely failed, and coal-gas had to be substituted. More recently the carburetting or carbonating system came into vogue, but hitherto it has proved unsuccessful. It would be wrong, however, to conclude that the above-mentioned processes of gas making must necessarily fail; for, as has frequently been found, a very slight alteration in the form or application of apparatus may produce most important results, and at length crown with success projects which had long been found impracticable for common use.

The defect which hitherto has been found insuperable alike in oil-gas and in the carbonating process has been the non-permanence of a considerable portion of the illuminating vapours thus produced in conveyance, in consequence of which the gas quickly loses a portion of its illuminating power, while the pipes are choked up by the deposit of the carbon constituents of the gas, rendering the process unworkable.

Of the new processes, or revivals of old methods, I may mention, firstly, the "air-gas," which is made by

passing common air through a closed vessel containing petroleum or resinous compounds, the volatile carbon vapours from which substances mix with the common air to such an extent as to render it illuminating.

Another of these methods is to produce hydrogen gas (which on being burnt yields great heat but hardly any light), and thereafter impart to it illuminating power by the carbonating process. One way of doing this is by conveying superheated steam into retorts containing a mixture of iron and coke raised to a high temperature. The steam (the constituents of which are oxygen and hydrogen) is thus decomposed, the oxygen combining with the iron and coke, while the hydrogen passes forward just as coal-gas does from the retorts, and thereafter is carbonated with the vapour of petroleum. Whatever be the fate of this invention, it is a trial in the right direction. As hitherto conducted, however, the process, or practical application of the principle, is open to serious objections. Firstly, a portion of the oxygen from the decomposed steam which unites with the coke in the retorts produces carbonic acid and passes forward with the hydrogen: this carbonic acid seriously reduces the illuminating power of gas, and although it can be easily removed by passing the gas through lime, the cost of doing so is undoubtedly a drawback upon the process. Secondly, a portion of the oxygen which unites with the coke in the retorts forms carbonic oxide, thereby largely increasing the amount of this substance (which is a deadly poison) which usually exists in coal-gas, and for the removal of which there are no known means.

A leakage of ordinary coal-gas has frequently proved fatal: indeed it has been found that the atmosphere of a bedroom becomes fatal to a sleeper although the admixture of gas is less than is requisite to render the air explosive, which is about 11 per cent. But if carbonic oxide be present to the extent in which it exists in the gas made by the above-mentioned process, a very small leakage of the gas might prove fatal.

Apart from the well-known difficulties attending the carbonating system (which is the chief feature in both of the above-mentioned inventions), owing to the liability of the illuminating vapours taken up by the air or gas passed through volatile oils to be partially deposited again in the pipes, with a corresponding reduction of the illuminating power of the gas, the important practical question remains: Will any of these new processes pay? It is impossible at present to give a decisive answer to this question: but an important consideration which must be taken into account is this: if petroleum or other carbonating substances come into use as substitutes for coal in gas making, the price of these substances will rise with the increased demand for them, so that the present price cannot be taken as a fixed element in computing the cost of working these new processes.

Another of the recent inventions was that of Dr. Eveleigh, known as the "patent gas," which excited extraordinary interest and temporarily found great favour with the public. The main feature and object of this invention was to convert into gas the greater part of the tar produced in ordinary gas making. The coal is

first distilled in retorts at a low temperature, whereby an unusual amount of tar is produced, with a correspondingly smaller quantity of gas, but of high illuminating power; thereafter the tar is placed in vessels where it is distilled and converted into gas, with the exception of a portion of it which is left in the form of pitch. The same questions apply to this invention as to the preceding ones, namely: First, is the gas made from the tar really permanent, or is a portion of it liable to be deposited in the pipes, with a corresponding loss of illuminating power? Secondly, supposing the process were successful, would the larger quantity of gas produced by the distillation of the tar more than compensate for the double process of distillation, and the greater number of retorts required owing to the low heats employed, and consequently the longer time required to distil a given quantity of coal? This "patent gas" was tried on a manufacturing scale at Barnet, where the works were inspected and the processes reported on by Dr. Odling and Mr. Keates. These eminent gas-chemists did not express any distinct opinion on the process, but some of the results obtained by them did not bear out the anticipations of the patentee; and ultimately the invention proved to be a failure.

The recent strike among the London gas-stokers has secured the fullest consideration for the project of substituting steam power for manual labour in the charging of retorts; and gas-stoking machines have obtained an extensive trial: but on the whole with disappointing results. The true source of economizing

labour of this kind seems to lie in a different direction, namely, the adoption of some method by which the retorts can be filled by a hopper at the top, and emptied simply by opening them at the bottom. Upright or vertical retorts of this kind have been patented by Messrs. Porter and Lane, with the important addition of an iron screw with oblique blade, revolving upon a vertical axis fixed in the centre of the retort. The coal is dropped by a hopper upon the blade of the screw, which, slowly revolving, keeps a spiral line of coal constantly in contact with the inner side of the retort, whereby the distillation is conducted in a more regular and perfect manner than by the ordinary retorts. This invention also has failed of success, chiefly owing to the metal screw being quickly damaged by the intense heat to which it is exposed.

Gas Testing.—The supply of gas to any town or district is practically a monopoly; for if competition be allowed, the double set of pipes required is a great inconvenience in the public streets, and is also an additional expense, which in the end falls upon the gas consumers. On this account Parliament now deals with the gas-supply in the manner requisite in regard to all other monopolies, by imposing conditions upon the gas companies to secure the interests of the public. Accordingly all the larger gas companies are gradually being placed under restrictions as to the quality of the gas which they supply.

Since the passing of the Metropolis Gas Act of 1868, a very perfect system of gas testing has been established in London; and although some of the London

gas companies are still exempt from this official testing, it must soon be extended over the whole of them. Under this system, a testing station is appointed for each gaswork by the Gas Referees, who give instructions as to the fitting-up of these stations, and also as to the mode in which the testings are to be conducted by the gas examiners, who are appointed by the municipal authorities. The testings are made daily, and there is a chief gas examiner, to whom appeal may be made by the gas companies. The testing stations so established are models of their kind, and show the perfection to which the entire apparatus of gas testing has now been brought.

Previous to 1868 the testings for sulphuretted hydrogen were made by exposing a test-slip of acetate of lead paper to the gas merely for about a minute. The gas referees extended the time during which the test-slip is exposed to the gas to three or five hours, whereby the testing was made much more stringent: for sulphuretted hydrogen acts cumulatively on acetate of lead in such manner that gas which appears perfectly pure when the slip is exposed to it for a minute or an hour, or even for twelve or twenty hours, will nevertheless stain the test-slip by longer exposure.

The testing for ammonia used likewise to be made by exposing a test-slip of turmeric paper to the gas for a few seconds. The gas referees made the testing for ammonia continuous for twenty hours, by passing the gas through a small cylinder containing small glass beads, and filled with a solution of sulphuric acid, by which means the whole of the ammonia is arrested, and

the exact quality of this impurity correctly determined. The referees at first allowed as a maximum 5 grains of ammonia per 100 feet of gas; but as soon as the companies had time to perfect their ammonia purificators, the referees reduced the maximum to 2½ grains: and the result is that the entire gas supply of London, so far as it is under the supervision of the referees, is now free from ammonia.

For what is technically called "sulphur," i. e. sulphur in other forms than sulphuretted hydrogen, the official or standard apparatus used to be Dr. Letheby's sulphur test, a simple and convenient apparatus, but which was known to be imperfect. The referees devised an apparatus, now known as the "referees' sulphur test," which is even more convenient for use than the Letheby instrument, and also detects 20 per cent. more sulphur in the gas. Mr. V. Harcourt has also produced a very perfect instrument, but troublesome in practice, very liable to breakage, and quite unsuitable for general use. This instrument was tried along with the referees' test, and a series of experiments showed that the results obtained were perfectly uniform (there being only half a grain of difference in favour of the referees' test), so that both of these instruments may be regarded as perfect, although Mr. Harcourt's instrument is wanting in the simplicity and conveniency which characterize the referees' test, which accordingly has been adopted as the standard.

The illuminating power of the gas likewise is daily ascertained in the testing stations by a series of testings extending over three hours in summer and five

hours in winter; and the burner employed in these testings is a Sugg's batwing for cannel gas, and for common gas a Sugg's "London" Argand, No. 1; and these burners are now generally adopted as the standard test-burners for common and cannel gas respectively.

Gas Lighting.

The price of gas varies with its illuminating quality; that for cannel gas being much higher than for common gas. In fact what gas companies give and what the public pays for, is not so much gas but so much Light. The companies supply the illuminating material, but the public are left to develope light from this material (namely, gas) in their own way, or as best they can. And hitherto they have done this very badly.

The late rise in the price of coal has directed attention to the great waste of heat occasioned by the very defective form of the grates in ordinary use: the result being the same as if the public threw away unused a large portion of the coal which they purchase. A still more striking, though less important, waste occurs in the employment of gas, owing to the multitude of very bad burners in general use.

In their investigations connected with the choice of a standard burner to be employed in the official testing stations, the gas referees made and tested a large collection of all kinds of burners obtained from the leading gas-fitting establishments; and on testing these burners, the startling fact was ascertained that the amount of light obtained from gas varied immensely—from 20

up to 100 per cent. In other words, some of the burners in general use gave only one-fifth part of the light given by the others; and the majority of them gave little more than one-half of the light which can be obtained from gas of the same quality when consumed in the best kind of burners; a fact which was corroborated by an examination which I made of the gas-lighting arrangements in some of the largest gas-consuming establishments in the City.

Every improvement in the construction of gas-burners is equivalent, in its economical effects, to a discovery of a method of cheapening the manufacture and supply of gas; for it enables the public to obtain more light from the gas which they consume and pay for. The improvement of burners is also important on sanitary principles; for as by this means the required amount of light is obtainable from a smaller quantity of gas, the atmosphere of rooms and workshops is proportionately less vitiated. In consequence of less gas being burnt, the pernicious products of combustion discharged into the air (viz. carbonic acid, the sulphur impurities, &c.) are equally diminished, so that the condition of the occupants of private dwellings, and still more of the workpeople employed in factories and other large establishments, is rendered more comfortable and more healthy than it could otherwise be.

Ever since the experiments of Christison and Turner in 1825, it used to be held that gas gives a larger proportion of light when it is burnt in large quantities than in small: in other words, that the larger the quantity of gas consumed in any kind of burner, the larger will be

the proportion of light obtained from the gas. Such a doctrine is plainly opposed to common sense, and to the ordinary course of nature: nevertheless the dogma held its ground, and most erudite disquisitions were published in support of it, and elaborate explanations offered of the alleged fact. Properly conducted investigations, however, made by the Gas Referees, have demonstrated the utter fallacy of this long prevalent doctrine, and have proved that the observed variations in the illuminating power of gas upon which the doctrine was based are entirely due to the burners. Every burner is fitted to consume a special quantity of gas of a given quality, just as a rifle is specially adapted for a special ball and charge of powder. And so utterly erroneous is the above-mentioned doctrine (latterly known as "Farmer's theorem"), that it might as well be reversed; for with many burners, indeed with all fishtail and batwing burners, the gas yields a larger proportion of light when it is consumed in smaller quantities than in larger ones. The correct statement of the matter is this, that with every burner there is a certain point of gas-consumption at which the burner gives *its* maximum of light, and that if the consumption be either increased or diminished from that point, the proportion of light obtained from the gas will be reduced. At the same time, as already said, even taking each kind of gas-burner at its best, the difference in the quality of the gas-burners in general use is so great, that some of them yield only one-fourth or one-fifth of the light obtainable from burners of the best construction.

The chief point to be observed alike in the construction and in the employment of burners, is the due regulation of the air-supply to the flame. This depends partly on the size and shape of the gas-flame,—for, of course, the larger the surface of the flame, the more is it brought in contact with the air; but still more upon the draught, whereby the same extent of surface will be more or less exposed to the action of the air. As regards Argands, the draught upon the flame is regulated to a great degree by the chimney or glass cylinder, which is indispensable for this kind of burner; but, partially as regards argands, and entirely as regards naked burners (i. e. fishtails and batwings), the air-supply is affected by the *pressure* under which the gas is burnt—in other words, by the velocity with which the gas issues from the burner. The stream of burning gas from the burner, rising through the quiescent atmosphere of the room, draws in the air upon itself, just as a rapid stream passing through a pool or lake disturbs the stillness of the pool, and draws in upon itself in eddies the surrounding water; and the more rapid the upward stream of gas (i. e. the greater the pressure under which it issues from the burner), the greater is the quantity of air thus drawn in upon the flame.

The richer the quality of the gas, the better does it bear contact with the air, because more oxygen is required to produce its perfect combustion. But with what is termed "common" gas—i. e. gas of from twelve to sixteen candle power—the difficulty is to *keep down* the air-supply, *inter alia*, by regulating the pressure of

the gas as supplied from the works. An excessive draught upon any flame tends to cool it, and *pro tanto* diminishes the vibratory movement of its atoms which produces light. Moreover, an excessive draught, such as is created when gas is burnt under high pressure, tends to mingle the air with the issuing gas-stream, producing, in a small degree, the results obtained from a Bunsen burner, a well-known apparatus for obtaining from gas a heat-giving and smokeless, but almost non-luminous, flame. It is usually held that the Bunsen burner yields a greater amount of heat than any other gas-flame; but experiments which I have made show that this is a mistake, and the explanation readily presents itself. Since, in the Bunsen burner, air is mingled with the gas below the point of ignition, the gas is diluted with one, and sometimes with two, incombustible elements,—namely, with the incombustible nitrogen, which forms three-fourths of the atmosphere, and also, in some cases, with an excess of oxygen, which, in so far as it is in excess, is likewise incombustible. Hence, in a Bunsen burner, the gas is diluted with one, and it may be with two, non-luminous bodies, which abstract a portion of the heat generated by the burning gas; so that the gas-flame cannot attain the heat, and consequently the intensity of luminiferous action, which it can do when burnt alone. Even so, though in an infinitely lesser degree, does an excessive draught upon the flame, produced by over-pressure or otherwise, diminish the amount of light obtained from gas consumed in ordinary burners.

To show the action of the air-supply upon a gas-

flame, and the remarkable variations in the size and luminosity of the flame so produced, take an Argand burner of the best kind—say, Sugg's London Argand, No. 1—consuming 5 feet an hour of sixteen-candle gas. Without its chimney or glass cylinder, the burner gives a waving yellow flame about 8 inches in height, and usually smoking. The gas-stream, in fact, extends itself upwards until, by the size of the flame, it comes in contact with the air to the requisite extent to produce entire, or almost entire, combustion of the gas. Put on a chimney of the most suitable kind for this quantity and quality of gas, and the height of the flame is at once reduced by one-half; nevertheless, the illuminating power of the flame is increased by one-half. The explanation is, that in the latter case the brilliancy of the flame, owing to the intensity of the combustion, is so much increased as to far more than compensate the diminution in the size of the flame. Instead of a tall, dull, yellow flame about 8 inches in height, we have a flame barely 4 inches high, of brilliant white, which gives one-half more light than the taller flame does. The cause of the shortening of the flame is the more rapid combustion of the gas, owing to the increased draught or air-supply produced by the use of the chimney. Being consumed in half the time, the gas-flame rises to only one-half its former height; but the increased intensity of combustion (in other words, the higher temperature at which the gas burns by obtaining an increased air-supply), produces a much greater amount of light from the shorter flame than from the taller

one. In this case, the air-supply is brought exactly to its proper amount. But if we still further increase the draught upon the flame, by using taller chimneys, opposite results commence. The brilliancy of the flame still continues to increase, but no longer to such an extent as to compensate for reduction in the size of the flame. Accordingly, while an increased draught or air-supply greatly increases the light of the gas-flame up to a certain point, any further increase of the draught seriously reduces the luminosity of the flame, thereby producing a waste of gas.

The effects of an inadequate draught or air-supply to the flame (however produced) are so readily noticeable, by the flame smoking or assuming a dull flagging appearance, that it is the fault of gas consumers themselves if this exist. But the case is very different as regards an excessive draught upon the flame—commonly but incorrectly termed "over-combustion"—whether of gas or of oil; for in this case there are no obvious signs of the waste that is then going on—the flame never smoking, and its colour being white and its form steady. Nevertheless, it is in this manner that the great waste of gas occurs. Indeed, it may be safely affirmed that about one-third of the whole gas-supply of the United Kingdom is thus wasted; and as the gas rental of the kingdom is probably about nine millions sterling, the serious character of this waste of gas is sufficiently obvious. The chief cause of the waste is the badness of the burners ordinarily supplied to the public by gasfitters; the second and subordinate cause is the ignorance on the part of the public

as to the proper manner of employing gas—or, in other words, of using good burners when they get them.

Until recently, the only idea entertained as to the construction of burners was to puncture their top in such a manner as to produce a smokeless flame; and the prevailing defect of the immense multitudes of burners still supplied to the public is, that the orifices are too small, in consequence of which the gas issues from the burner under an excessive pressure, the effect being, as already said, to subject the flame to an excessive draught. Moreover, until recently, gasfitters (as well as more learned men) were so ignorant of the principles of gas combustion, that they made little difference in the kind of burners which they supplied, however great might be the difference in the richness of the gas or the quantity which was meant to be consumed: whereas, as has now been demonstrated, even the best-constructed burners fail to develope the full amount of light from gas, unless the quantity or quality of the gas is precisely such as the burners are specially designed or fitted to consume.

Within the last five or six years a great improvement has been made in the construction and fitting up of burners, but as yet the work is well done only by a very few of the numerous gasfitting establishments. Mr. Sugg, of Westminster, who has thoroughly investigated the subject, has produced a series of Argand burners, for consuming different quantities and qualities of gas, which may be regarded as absolutely perfect, and the light which they give is the most pleasant and beautiful which can possibly be obtained from gas.

His naked burners, i. e. fishtails and batwings, are also excellent; but in this department he has able competitors in Mr. Leoni, of London, and also in the burners from the German manufactory of Bronner. In all good burners there is an apparatus by which the pressure of the gas is more or less checked prior to the point of ignition, in order that the gas may issue from the orifices of the burner with no more pressure than is indispensable to produce a steady flame. The principle of this apparatus is very simple, and consists chiefly in making the orifice at the bottom of the burner of smaller size than the orifice at the top from which the gas issues. The kind of apparatus by which this object is attained varies greatly. Sometimes small perforated metal discs are placed in the burner, sometimes merely bits of wool, to check the flow of gas. Bronner simply makes the orifice at the bottom of his batwings smaller than the orifices at the top,—the respective size of the orifices varying in such a manner that by using one or other of his series, it will prove suitable for any locality or pressure. Mr. Sugg prefers to supply a cone which can be adapted to any pressure, simply by screwing it into the burner to a greater or lesser extent. By this means Mr. Sugg's burners can be readily adapted to every locality, whereupon they produce an economy of gas and at the same time yield an excellent light.

The first point, then, for gas consumers is to supply themselves with really good burners; and although the cost of such burners is much greater than that of the ordinary bad ones, the extra cost

is far more than repaid by the saving in the gas bill, while at the same time the light yielded is in all respects satisfactory. The next point for the gas consumer is to take care that the good burners are properly fitted up; and in many parts of the kingdom, nay in London itself, there are very few gasfitting establishments whose workmen have the knowledge (simple though it be) for fitting up burners in the manner demanded by the circumstances of each locality, —that is to say, by the average pressure at which the gas is supplied to any particular street or house, which is greater in proportion as the house is above the level of the gasworks. Sugg's men can do this admirably, and I doubt not the establishments of Leoni and of Bronner (whose London agent is Mr. Greene) may also be trusted in this important branch of gasfitting.

But more than this requires to be done. After good burners have been obtained, and also properly fitted up, there remains this difficulty, that great variations occur every night in the pressure at which the gas is supplied. The burners, if properly adjusted, will consume the gas admirably so long as the gas is supplied at the ordinary pressure for the particular house or locality; but, as everyone must have noticed, the pressure or supply of gas varies greatly in the course of the evening. For example, in winter, if a burner has been lighted before actual darkness sets in, soon afterwards the flame will suddenly flare up and smoke, although the tap has not been altered. This is owing to the pressure for the night being put on at the gasworks, whereby, although the orifice of the tap

remains the same, perhaps double the quantity of gas is passed through it. In like manner, towards midnight, just after the shops and theatres close, a similar rush of gas takes place, and continues until the time when the pressure at the gasworks is taken off. These and all other variations in the pressure or supply of gas can be wholly nullified in their action upon the burners by the use of a "governor,"—a self-acting apparatus, so constructed that every increase in the supply or pressure of the gas forces up a cone farther into the inlet for the gas, proportionately narrowing the inlet, and thereby maintaining the pressure or supply of gas within the house perfectly steady and uniform.

However skilfully burners may be fitted up in a house, the difference between good and bad burners cannot possibly be overcome. The use of good burners is indispensable to obtain the full amount of light from gas. The governor, however, *might* be dispensed with if a constant and intelligent attention were paid to regulating the tap or cock which admits the gas to each burner. Theoretically the tap can be made to take the place of the governor, for by means of the tap the pressure or supply of gas to each burner can be increased or diminished at pleasure. Nevertheless, as a practical question, the governor is indispensable to the perfect use of burners; for although a gas consumer may be trusted to turn down the tap when his burners actually smoke, there are no adequate signs (as already explained) to warn him when a waste of gas is taking place owing to the gas being burnt under too high a pressure; and this is especially the case with the

burners in most general use, viz. fishtails and batwings, which rarely smoke, however excessive may be the quantity of gas passing through them. Hence a governor ought to be employed in every house. But as it is beyond expectation that the occupiers of small houses will incur the cost of a "governor," it is important that the uses of the tap as a substitute for a governor should be properly understood. In nine cases out of ten, at present, the tap is placed close to the burner, whereas, in order to turn it to proper account, the tap ought to be placed as far from the burner as is conveniently possible, say, not less than 18 inches apart. By this means the portion of the tube between the tap and the burner is converted into a chamber wherein the gas is brought comparatively to a state of rest, and from which it feeds the burner with a steady and equable flow, which is requisite to the production of the proper amount of light from the gas.

Having thus explained matters, let me conclude by showing what is the best and the only thoroughly satisfactory, method of lighting a house with gas. A governor is placed (say beside the meter) on the pipe which admits the gas into the house; by which means the pressure of the gas supplied to the house can be maintained at an invariable point. Good burners are then fitted up in the various rooms in such a manner, that each of them will give its maximum amount of light under the fixed pressure of the gas as regulated by the governor. It may here be mentioned that, even if exactly the same kind of burners were used through-

out the house, they would require to be *fitted up* differently in each floor; for every twenty feet in altitude occasions a sensible increase in the pressure of the gas. The manner in which burners are "fitted" to their respective localities has already been explained; the principle being simply, that they are adjusted so that the gas is supplied to and issues from their orifices under no more pressure than is necessary to produce a steady and smokeless flame. In a house so fitted up the taps can be at all times fully opened, and do not require to be altered or attended to in any way; an advantage of the greatest importance alike as regards convenience, economy, and cleanliness.

Highly valuable as would be any successful inventions for cheapening the manufacture of gas, I feel assured that the public have the means of cheapening gas for themselves, by a proper use of it, to a greater extent than can at present be looked for from any improvements in the mode of producing it. By the employment of good burners, properly fitted up, the public can obtain at least one-third more light than hitherto from the gas, which is equivalent to a reduction of one-third in the price of gas. Such a change, however, will progress but slowly. It will take a good many years before the mass of the gas-consuming public become alive to the true facts of the case; and, until then, the attractions of a very bad burner costing little more than a penny will outweigh with them the far greater ulterior economy of gas by the use of good burners costing a shilling or more. Nine-tenths of the complaints against gas companies for supplying gas of

inadequate illuminating quality are groundless, and are attributable to the now perfectly ascertained fact that the vast majority of burners in general use, I may say hardly one in ten thousand, are incapable of developing the proper amount of light from gas. The remedy for this great waste, though it may come slowly, will come surely. Thereafter the only drawback upon the use of gas is one which the companies themselves are bound to overcome, namely, the supply of gas of proper *purity*. Over the greater part of London, gas is now supplied perfectly free from sulphuretted hydrogen, and almost equally free from ammonia; and recently, as already explained, the long-standing difficulty of the obnoxious sulphur impurity has likewise been overcome in such a manner that gas may now be purified to the fullest extent, and by methods which may be employed without occasioning nuisance even in the heart of a city.

LONDON: PRINTED BY EDWARD STANFORD, 55, CHARING CROSS, S.W.

SELECTED LIST OF EDWARD STANFORD'S PUBLICATIONS,

55, CHARING CROSS, LONDON.

Books.

ADDERLEY.—COLONIAL POLICY and HISTORY—REVIEW of "The COLONIAL POLICY OF LORD J. RUSSELL'S ADMINISTRATION, BY EARL GREY, 1853," and of SUBSEQUENT COLONIAL HISTORY. By the Right Hon. Sir C. B ADDERLEY, K.C.M.G., M.P. Demy 8vo, cloth, 9s.

ANSTIE.—THE COAL FIELDS OF GLOUCESTERSHIRE AND SOMERSETSHIRE, AND THEIR RESOURCES. By JOHN ANSTIE, B A., F.G.S., Ass. Inst Civil Engineers, &c. With Tables and Sections. Imperial 8vo, cloth, 6s.

ANTHROPOLOGICAL NOTES and QUERIES. For the Use of Travellers and Residents in Uncivilized Lands. Drawn up by a Committee appointed by the British Association for the Advancement of Science. Fcap. 8vo, cloth, leather back, 5s.

BARFF.—ELEMENTARY CHEMISTRY. By F. S. BARFF, M.A., Christ's College, Cambridge; Professor of Chemistry at the Royal Academy of Arts. With Illustrations. Fcap. 8vo cloth, 1s. 6d.

BEVAN.—TOURISTS' GUIDE TO THE COUNTY OF KENT. By G. PHILLIPS BEVAN, F.G.S. With Map and Two Plans. Fcap. 8vo, limp cloth, 2s.

BELLAMY.—TABLES FOR THE USE OF ENGINEERS AND ARCHITECTS in Taking out QUANTITIES of MASONRY, IRONWORK, &c. By C. J. BELLAMY, C.E. Royal 8vo, cloth, 15s.

BOWRING.—The DECIMAL SYSTEM, in NUMBERS, COINS, and ACCOUNTS. By the late Sir JOHN BOWRING, LL.D. Illustrated with 120 Engravings of Coins, Ancient and Modern. Post 8vo, cloth, 4s.

BRAZILIAN COLONIZATION, from an EUROPEAN POINT of VIEW. By JACARÉ ASSU. Demy 8vo, cloth, 2s. 6d.

BROWN.—CANOE AND CAMP LIFE IN BRITISH GUIANA. By C. BARRINGTON BROWN, Associate of the Royal School of Mines, late Government Surveyor in British Guiana. Demy 8vo, cloth, with Map and 10 Coloured Illustrations, 21s.

COOTE.—THREE MONTHS in the MEDITERRANEAN. By WALTER COOTE. Crown 8vo, cloth, 5s.

CRACROFT.—TRUSTEE'S GUIDE: A SYNOPSIS of the Ordinary Powers of Trustees in regard to Investments, with Practical Directions and Tables of Securities. By BERNARD CRACROFT. Twelfth Edition, enlarged. Fcap. 4to, cloth, 7s. 6d.

DENNIS.—STUDIES IN ENGLISH LITERATURE. By John Dennis, Editor of 'English Sonnets: a Selection from 1547,' &c. Crown 8vo, cloth, 7s. 6d.

DE RICCI.—FIJI: Our New Province in the South Seas. By J. H. De Ricci, F.R.G.S., H.M.'s Attorney-General for Fiji; Author of 'How about Fiji?' With two Maps. Large post 8vo, cloth, 9s.

DREW.—THE JUMMOO AND KASHMIR TERRITORIES. A Geographical Account. By Frederic Drew, F.R.G.S., F.G.S., Associate of the Royal School of Mines; late of the Maharaja of Kashmir's Service. Illustrated by Six Folding Coloured Maps, numerous Plates and Folding Sections. Medium 8vo, cloth, 42s.

—— THE NORTHERN BARRIER OF INDIA. A Popular Account of the Jummoo and Kashmir Territories. By Frederick Drew, F.R.G.S., F.G.S., &c., &c. With Map and numerous Illustrations. Large Post 8vo, cloth, 12s.

DUN.—BRITISH BANKING STATISTICS; with Remarks on the Bullion Reserve and Non-Legal-Tender Note Circulation of the United Kingdom By John Dun, General Manager of Parr's Banking Company, Limited. Demy 8vo, 5s.

EDWARDS.—THE GERMANS IN FRANCE. Notes on the Method and Conduct of the Invasion; the Relations between Invaders and Invaded; and the Modern Usages of War. By H. Sutherland Edwards. Post 8vo, cloth, 10s. 6d.

ELEMENTARY ATLASES:—

ELEMENTARY PHYSICAL ATLAS, intended chiefly for Map-Drawing, and the study of the Great Physical Features and Relief Contours of the Continent. By the Rev. J. P. Faunthorpe, M.A., F.R.G.S., Principal of Whitelands Training College. Seventh Edition, 16 Maps, printed in Colour, with descriptive Letterpress. Price 4s.

OUTLINE ATLAS.—Containing Sixteen Maps. By the Rev. J. P. Faunthorpe, M.A., F.R.G.S., Principal of Whitelands Training College. Coloured Wrapper, 1s.

PROJECTION ATLAS.—Containing Sixteen Plates of Projections. By the Rev. J. P. Faunthorpe, M.A., F.R.G.S., Principal of Whitelands Training College. Coloured Wrapper, 1s.

BLANK SHEETS for MAPS.—Sixteen Leaves of Blank Paper for Map-Drawing. Coloured Wrapper, 6d.

PHYSICAL ATLAS.—A Series of Twelve Maps for Map-Drawing and Examination. By Charles Bird, B.A., F.R.A.S., Science Master in the Bradford Grammar School. Royal 4to, stiff boards, cloth back, 4s. 6d.

EVILL.—A WINTER JOURNEY to ROME and BACK. With Glances at Strasburg, Milan, Florence, Naples, Pompeii, and Venice. Third Edition, with Map and Appendix. Crown 8vo, cloth, 4s. 6d.

FOSTER.—MANUAL of GEOGRAPHICAL PRONUNCIATION and ETYMOLOGY. By A. F. Foster, A.M., Author of 'A General Treatise on Geography,' &c. Ninth Edition. Fcap. 12mo, limp cloth, 2s.

GAWLER.—SIKHIM. With Hints on Mountain and Jungle Warfare. By Colonel J. C. Gawler, F.R.G.S., late Deputy Adjutant-General in India. With Map and Illustrations. Demy 8vo, paper, 3s.; cloth, 3s. 6d.

GILL.—CHEMISTRY for SCHOOLS: an Introduction to the Practical Study of Chemistry. By C. HAUGHTON GILL, late Assistant Examiner in Chemistry at the University of London. Third Edition. One Hundred Illustrations. Crown 8vo, cloth, 4s 6d.

GREEN.—VESTIGES of the MOLTEN GLOBE, as Exhibited in the Figure of the Earth, Volcanic Action, and Physiography. By WILLIAM LOWTHIAN GREEN, Minister of Foreign Affairs to the King of the Sandwich Islands. Demy 8vo, cloth, 6s.

HOLDSWORTH.—DEEP-SEA FISHING and FISHING BOATS. An Account of the Practical Working of the various Fisheries carried on around the British Islands. With Illustrations and Descriptions of the Fishing Boats, Nets, and other gear in use; and Notices of the Principal Fishing Stations in the United Kingdom. By EDMUND W. H. HOLDSWORTH, F.L.S., F.Z.S., &c., late Secretary to the Royal Sea Fisheries Commission. Medium 8vo, cloth, 21s.

HULL.—COAL FIELDS of GREAT BRITAIN; their History, Structure, and Resources; with Notices of the Coal Fields of other parts of the World. By EDWARD HULL, M.A., F.R.S., Director of the Geological Survey of Ireland, Professor of Geology in the Royal College of Science, Dublin, &c. With Maps and Illustrations. Third Edition, revised and enlarged. Demy 8vo, cloth, 16s.

JENKINSON.—PRACTICAL GUIDE to the ENGLISH LAKE DISTRICT. With Nine Maps and Three Panoramic Views. With Chapters on Local Names—Meteorology, Geology, and Botany. Fifth Edition. Fcap. 8vo, cloth, 6s.

*** The SECTIONS separately: KESWICK—WINDERMERE and LANGDALE—CONISTON, BUTTERMERE, and WASTWATER—GRASMERE and ULLSWATER. With Maps, price 1s. 6d. each

— SMALLER PRACTICAL GUIDE to the ENGLISH LAKE DISTRICT: Fcap. 8vo, with Map, 1s. 6d

— PRACTICAL GUIDE to the ISLE OF MAN. With Chapters on Local Names, Mineralogy, Civil History, Ecclesiastical History, Geology, Botany, Zoology, Agriculture, Commerce, and Sea Trout-fishing. With Map. Fcap. 8vo, cloth, 5s.

— SMALLER PRACTICAL GUIDE to the ISLE OF MAN. With Map. Fcap 8vo, 2s.

— PRACTICAL GUIDE to CARLISLE, GILSLAND, the ROMAN WALL, and NEIGHBOURHOOD. By H. J. JENKINSON. With Chapters on Local Names, Geology, Mineralogy, Botany, and Entomology. Map and Frontispiece. Fcap. 8vo, cloth, 5s.

— SMALLER PRACTICAL GUIDE to CARLISLE and NEIGHBOURHOOD. With Map. Fcap. 8vo, 2s.

— PRACTICAL GUIDE to the ISLE OF WIGHT. With Chapters on Local Names, History, Mineralogy, Archæology, Botany, Geology, Natural History, Commerce, Agriculture, Sea Fishing, and Yachting. Fcap. 8vo, cloth, with Frontispiece and 6 Maps, 5s.

— SMALLER PRACTICAL GUIDE to the ISLE OF WIGHT. With Two Maps. Fcap. 8vo, 2s.

KING.—VIRGIL'S ÆNEID: Translated into English Verse by the Rev. J. M. KING, Vicar of Cutcombe, late Scholar of Ball. Coll., Oxon. Second Edition. Crown 8vo, cloth, 7s. 6d.

LEECH.—IRISH RIFLEMEN in AMERICA. By ARTHUR BLENNERHASSETT LEECH. With Coloured Plates and a Map. Crown 8vo, cloth, 6s.

LEWIS.—The ENGLISH LANGUAGE: Its GRAMMAR and HISTORY; together with a TREATISE on ENGLISH COMPOSITION, &c. By the Rev. HENRY LEWIS, B.A., Principal of Culham Training College. Sixth Edition. Fcap. 8vo, cloth, 3s.

—— ENGLISH GRAMMAR for BEGINNERS, in a SERIES of EASY LESSONS. By the Rev. HENRY LEWIS, B.A., Principal of Culham Training College. Intended for the use of Junior Classes, and as an Introduction to the Author's larger English Grammar. Second Edition. Fcap. 8vo, 2d.

LEWIS.—DIGEST OF THE ENGLISH CENSUS OF 1871, compiled from the Official Returns and Edited by JAMES LEWIS (of the Registrar-General's Department, Somerset House). Sanctioned by the Registrar-General, and dedicated by permission to the President, Vice-Presidents, and Council of the Statistical Society of London. Royal 8vo, cloth, 5s.

LONDON GUIDE AND MAP. How to get from or to any part of London, or its Suburbs, Public Building, Place of Worship, Exhibition, Institution, Place of Amusement, &c.; with Times, Fares, Prices of Admission, Specialty, &c. Printed in colours. New Edition, 1876. Crown 8vo, cloth, 3s. 6d.

LUCAS. — HORIZONTAL WELLS: A New Application of Geological Principles to effect the Solution of the Problem of Supplying London with Water. By J. LUCAS, F.G.S., of the Geological Survey of England. With Maps. Crown 4to, cloth back, 10s. 6d.

MANLY.—PRINCIPLES of BOOK-KEEPING by DOUBLE ENTRY, in a Series of Easy and Progressive Exercises. By the late HENRY MANLY. Fourth Edition. Revised and enlarged by HENRY WILLIAM MANLY, F.I.A. Demy 8vo, cloth, 4s. 6d.

MARTIN.—THEORIES of HORIZONTAL CURRENTS in the OCEAN and ATMOSPHERE, and of Eastation of Planetary and other Celestial Bodies. By JOHN MARTIN, of Melbourne. 17 Illustrations. Crown 8vo, cloth, 3s.

MEADEN.—A FIRST ALGEBRA for Use in Junior Classes. By the Rev. R. ALBAN MEADEN, M.A., Senior Mathematical Master of the Bradford Grammar School. Fourth Edition, revised and enlarged. Fcap. 8vo, cloth, 1s. 6d.

MEDHURST.—The FOREIGNER in FAR CATHAY. By W. H MEDHURST, H.B.M. Consul, Shanghai. With Coloured Map. Crown 8vo, cloth, 6s.

MILLETT.—An AUSTRALIAN PARSONAGE; or, the SETTLER and the SAVAGE in WESTERN AUSTRALIA. With Frontispiece. By Mrs. EDWARD MILLETT. Second Edition. Large post 8vo, cloth, 12s.

MULHALL.—HANDBOOK TO THE RIVER PLATE REPUBLICS: Comprising Buenos Ayres and the Provinces of the Argentine Republic, and the Republics of Uruguay and Paraguay. By M. G. and E. T. MULHALL, Proprietors and Editors of the Buenos Ayres 'Standard.' With Map and Two Plans. Crown 8vo, cloth, 8s.

NOBLE.—DESCRIPTIVE HANDBOOK OF THE CAPE COLONY: Its Condition and Resources. By JOHN NOBLE, Clerk of the House of Assembly, Cape of Good Hope. With Map and Illustrations. Crown 8vo, cloth, 10s. 6d.

PALMER.—The ORDNANCE SURVEY of the KINGDOM: Its Objects, Mode of Execution, History, and Present Condition. By Captain H. S. PALMER, R.E. Five Coloured Index Maps. Demy 8vo, cloth, 2s. 6d.

PHILPOT.—GUIDE BOOK to the CANADIAN DOMINION: Containing full information for the Emigrant, the Tourist, the Sportsman, and the small Capitalist. By HARVEY J. PHILPOT, M.D. (Canada), M.R.C.S.L., &c. With a Preface by THOMAS HUGHES, Esq., M.P., and Map. Super-royal 16mo, 4s.

POOR RELIEF IN DIFFERENT PARTS OF EUROPE: being a Selection of Essays, translated from the German Work, 'Das Armenwesen und die Armengesetzgebung in Europäischen Staaten herausgegeben,' Von A. Emminghaus. Revised by E. B. EASTWICK, C.B., M.P. Crown 8vo, cloth, 7s.

RAMSAY.—PHYSICAL GEOLOGY and GEOGRAPHY of GREAT BRITAIN. By A. C. RAMSAY, LL.D., F.R.S., &c., Director-General of the Geological Surveys of the United Kingdom. Fourth Edition, considerably enlarged, and Illustrated with NUMEROUS SECTIONS and a GEOLOGICAL MAP of GREAT BRITAIN, printed in Colours. Post 8vo, cloth 7s. 6d.

ROBSON.—CONSTRUCTIVE LATIN EXERCISES, for Teaching the Elements of the Language on a System of Analysis and Synthesis, with Latin Reading Lessons and copious Vocabularies. By JOHN ROBSON, B.A. Lond., Secretary of University College, London. Ninth Edition. 12mo, cloth, 4s. 6d.

—— FIRST GREEK BOOK. Containing Exercises and Reading Lessons on the Inflexions of Substantives and Adjectives. With copious Vocabularies. By JOHN ROBSON, B.A. Lond. Third Edition. 12mo, cloth, 3s. 6d.

ROWAN.—THE EMIGRANT AND SPORTSMAN IN CANADA. Some experiences of an Old Country Settler. With Sketches of Canadian Life, Sporting Adventures, and Observations on the Forests and Fauna. By J. J. ROWAN. Large post 8vo, cloth, with Map, 10s. 6d.

RUSSELL.—BIARRITZ and the BASQUE COUNTRIES. By COUNT HENRY RUSSELL, of the Alpine Club, and Société Ramond, Author of 'Pau and the Pyrenees,' &c. Crown 8vo, with a Map, 6s.

SCHOOL-BOYS' LETTERS for COPYING and DICTATION: being a Series of Lithographed Letters on Subjects interesting to School-Boys, with Remarks on the Essentials of Good Writing, &c. Third Edition. Large post 8vo, cloth, 2s. 6d.

SHARP.—RUDIMENTS of GEOLOGY. By SAMUEL SHARP, F.S.A., F.G.S. Introductory and Physical—Stratigraphical and Palæontological. Second Edition, revised and enlarged. Crown 8vo, cloth, 1s.

SULLIVAN.—THE PRINCES OF INDIA. An Historical Narrative of the principal events from the Invasion of Mahmoud of Ghizni to that of Nadir Shah. By Sir EDWARD SULLIVAN, Bart., Author of 'Letters on India,' 'Trip to the Trenches,' 'Rambles in North and South America,' &c. Second Edition. Crown 8vo, cloth, with Map, 8s. 6d.

SHERRY.—FROM VINEYARD to DECANTER. A Book about Sherry. By DON PEDRO VERDAD. With a Map of the Jerez District. 5th Thousand. Fcap 8vo, cloth, 1s.

WILLIAMS.—THROUGH NORWAY WITH A KNAPSACK. A New and Improved Edition. By W. M. WILLIAMS, F.R.A.S., F.C.S., &c. Crown 8vo, cloth, with Frontispiece and Map, 6s.

Library or Wall Maps.

EUROPE.—Scale, 50 miles to an inch; size, 65 inches by 58. Coloured and mounted on linen, in morocco case, 3*l.* 13*s.* 6*d.*; on roller, varnished, 3*l.*; spring roller, 6*l.*

ENGLAND and WALES.—Scale, 5 miles to an inch, size, 72 inches by 84. Coloured, 2*l.* 12*s.* 6*d.*; mounted on linen, in morocco case, 3*l.* 13*s.* 6*d.*; on roller, varnished, 4*l.* 4*s.*; spring roller, 6*l.* 6*s.*

LONDON and its SUBURBS.—On the scale of six inches to a mile: constructed on the basis of the Ordnance block plan. Price, in sheets, plain, 21*s.*; coloured, in a portfolio, 31*s.* 6*d.*; mounted on linen, in morocco case, or on roller, varnished, 2*l.* 15*s.*; on spring roller, 5*l.* 5*s.* Single sheets, plain, 1*s.*; coloured, 1*s.* 6*d.* A Key Map may be had on application, or per post for one stamp.

SCOTLAND.—Scale, five miles to an inch; size, 52 inches by 76. Coloured, 42*s.*; mounted on linen, in morocco case, 3*l.* 3*s.*; on roller, varnished, 3*l.* 13*s.* 6*d.*; spring roller, 5*l.* 5*s.*

IRELAND.—Scale, 4 miles to an inch; size, 66 inches by 81. Coloured, 1*l.* 11*s.* 6*d.*; mounted on linen, in morocco case, 2*l.* 12*s.* 6*d.*; or, on roller, varnished, 3*l.* 3*s.*; spring roller, 5*l.* 5*s.*

ASIA.—Scale, 110 miles to an inch; size, 65 inches by 58. Coloured and mounted on linen, in morocco case, 3*l.* 13*s.* 6*d.*; on roller, varnished, 3*l.*; spring roller, 6*l.*

AFRICA.—Scale, 94 miles to an inch; size, 58 inches by 65. Coloured and mounted on linen, in morocco case, 3*l.* 13*s.* 6*d.*; on roller, varnished, 3*l.*; spring roller, 6*l.*

NORTH AMERICA.—Scale, 83 miles to an inch; size, 58 inches by 65. Coloured and mounted on linen, in morocco case, 3*l.* 13*s.* 6*d.*; on roller, varnished, 3*l.*; spring roller, 6*l.*

CANADA.—LARGE MAP of CANADA, including New Brunswick, Nova Scotia, Newfoundland, and a large portion of the United States. By JOHN ARROWSMITH. Scale, 15¼ miles to an inch; size, 96 inches by 54. Eight Coloured Sheets.

UNITED STATES and CENTRAL AMERICA, with Canada, New Brunswick, Nova Scotia, Newfoundland, and the West Indies. Scale, 54½ miles to an inch; size, 72 inches by 56. Coloured and mounted on linen, in morocco case, 3*l.* 13*s.* 6*d.*; on roller, varnished, 3*l.*; spring roller, 6*l.*

SOUTH AMERICA.—Scale, 83 miles to an inch; size, 58 inches by 65. Coloured and mounted on linen, morocco case, 3*l.* 13*s.* 6*d*: on roller, varnished, 3*l.*; spring roller, 6*l.*

AUSTRALASIA.—Scale, 64 miles to an inch; size, 65 inches by 58. Coloured and mounted on linen, morocco case, 3*l.* 13*s.* 6*d.*; on roller, varnished, 3*l.*; spring roller, 6*l.*

General Maps.

EUROPE.

EUROPE.—STANFORD'S PORTABLE MAP of EUROPE; showing the latest Political Boundaries, the Railways, the Submarine Telegraphs, &c. Scale, 150 miles to an inch; size, 36 inches by 33. Fully coloured and mounted on linen, in case, 10s.; on roller, varnished, 11s.

CENTRAL EUROPE.—DAVIES'S MAP of CENTRAL EUROPE; containing all the Railways, with their Stations. The principal roads, the rivers, and chief mountain ranges are clearly delineated. Scale, 24 miles to an inch; size, 47 inches by 38. Sheets, plain, 10s.; coloured, 12s.; mounted on linen, in case, 16s.

AUSTRIAN EMPIRE. By J. ARROWSMITH. Scale, 28 miles to an inch; size, 26 inches by 22. Sheet, coloured, 3s.; mounted in case, 5s.

DENMARK and ICELAND. By J. ARROWSMITH. Scale, 13 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3s.; mounted in case, 5s.

FRANCE, in DEPARTMENTS. With a Supplementary Map, divided into Provinces, and a Map of the Island of Corsica. By J. ARROWSMITH. Scale, 31 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3s.; mounted in case, 5s.

GREECE and the IONIAN ISLANDS. By J. ARROWSMITH. Scale, 15 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3s.; mounted in case, 5s.

ITALY, including Sicily and the Maltese Islands. By J. ARROWSMITH. Scale, 20 miles to an inch; in two sheets, size of each 22 inches by 26. Price of each, coloured, 3s.; mounted in case, 5s.

NETHERLANDS and BELGIUM, including Luxembourg and the Country to the East as far as the Rhine. By J. ARROWSMITH. Scale, 13 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3s.; mounted in case, 5s.

RUSSIA and POLAND, including Finland. By J. ARROWSMITH. Scale, 90 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3s.; mounted in case, 5s.

SPAIN and PORTUGAL. By J. ARROWSMITH. Scale, 30 miles to an inch; size, 26 inches by 22. Sheet, coloured, 3s.; mounted in case, 5s.

SWEDEN and NORWAY. By J. ARROWSMITH. Scale, 35 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3s.; mounted in case, 5s.

SWITZERLAND. By J. ARROWSMITH. Scale, 10½ miles to an inch; size, 26 inches by 22. Sheet, coloured, 3s.; mounted in case, 5s.

TURKEY in EUROPE, including the Archipelago, Greece, the Ionian Islands, and the South part of Dalmatia. By J. ARROWSMITH. Scale, 40 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3s.; mounted in case, 5s.

BRITISH ISLES.

ENGLAND and WALES.—LARGE SCALE RAILWAY and STATION MAP of ENGLAND and WALES. In 24 sheets (sold separately). Constructed on the basis of the trigonometrical survey. By J. ARROWSMITH. Scale, 3 miles to an inch; size of each sheet, 20 inches by 28. Price, plain, 1*s.*; mounted in case, 2*s.* 6*d.*; coloured, 1*s.* 6*d.*; mounted in case, 3*s.* Size of the complete map, 114 inches by 128. Price, plain, in case or portfolio, 1*l.* 5*s.*; coloured, in case or portfolio, 1*l.* 8*s.*; mounted on cloth to fold, in case, coloured, 4*l.* 4*s.*; on canvas, roller, and varnished, 4*l.* 14*s.* 6*d.*: on spring roller, 9*l.* 9*s.*

ENGLAND and WALES.—STANFORD'S PORTABLE MAP of ENGLAND and WALES. With the Railways very clearly delineated; the Cities and Towns distinguished according to their Population, &c. Scale, 15 miles to an inch; size, 28 inches by 32. Coloured and mounted on linen, in case, 5*s.*; or on roller, varnished, 8*s.*

WALES.—NORTH and SOUTH WALES. Re-issue of Walker's Maps, thoroughly revised and corrected to the present date. Scale, 3 miles to an inch. Each in sheet, 32 inches by 27, coloured, 3*s.*; mounted to fold in case for the pocket, 6*s.*

SCOTLAND, in COUNTIES. With the Roads, Rivers, &c. By J. ARROWSMITH. Scale, 12 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3*s.*; mounted in case, 5*s.*

IRELAND, in COUNTIES and BARONIES, on the basis of the Ordnance Survey and the Census. Scale, 8 miles to an inch; size, 31 inches by 38. On two sheets, coloured, 8*s.*; mounted on linen, in case, 10*s.* 6*d.*; on roller, varnished, 15*s.*

IRELAND, in COUNTIES. With the Roads, Rivers, &c. By J. ARROWSMITH. Scale, 12 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3*s.*; mounted in case, 5*s.*

LONDON.

COLLINS' STANDARD MAP of LONDON is admirably adapted for visitors to the City. Scale, 4 inches to a mile; size, 34½ inches by 27. Price, plain, in case, 1*s.*; coloured, 1*s.* 6*d.*; mounted on linen, ditto, 3*s.* 6*d.*; on roller, varnished, 7*s.* 6*d.*

BRITISH METROPOLIS.—DAVIES'S NEW MAP of the BRITISH METROPOLIS. Scale, 3 inches to a mile; size, 36 inches by 25½. Price, plain sheet, 3*s.* 6*d.*; coloured, 5*s.*; mounted on linen, in case, 7*s.* 6*d.*; on roller, varnished, 10*s.* 6*d.* With continuation southward beyond the Crystal Palace, plain sheet, 5*s.*; coloured, 7*s.* 6*d.*; mounted on linen, in case, 11*s.*; on roller, varnished, 15*s.*

RAILWAY MAP of LONDON and ENVIRONS.—STANFORD'S SPECIAL MAP of the RAILWAYS, RAILWAY STATIONS, TRAMWAYS, POSTAL DISTRICTS, and SUB-DISTRICTS, in LONDON and its ENVIRONS. Scale, 1 inch to a mile; size, 24 inches by 26. Price, coloured and folded, 1*s.*; mounted on linen, in case, 3*s.*

ENVIRONS of LONDON.—DAVIES'S MAP of the ENVIRONS of LONDON. Scale, 1 inch to a mile; size, 43 inches by 32. Price, sheet, plain, 4*s.*; coloured 5*s.* 6*d.*; mounted on linen, in case, 8*s.*; or on roller, varnished, 14*s.*

ASIA.

GENERAL MAP OF ASIA.—By J. ARROWSMITH. Scale, 300 miles to an inch; size, 26 inches by 22. Sheet, coloured, 3*s.*; mounted, in case, 5*s.*

NORTHERN ASIA, including Siberia, Kamtschatka, Japan, Mantchooria, Mongolia, Tchoongaria, Tibet, and the Himalaya Mountains. By J. ARROWSMITH. Scale, 170 miles to an inch; size, 26 inches by 26. Sheet, coloured, 4*s.*; mounted, in case, 7*s.*

CENTRAL ASIA.—STANFORD'S MAP of CENTRAL ASIA, including Teheran, Khiva, Bokhara, Kokan, Yarkand, Kabul, Herat, &c. Scale, 110 miles to an inch; size, 22 inches by 17. Coloured sheet, 2*s.* 6*d.*; mounted, in case, 5*s.*

ASIA MINOR, &c. (TURKEY in ASIA). With portions of Persia, the Caspian Sea, and the Caucasian Mountains. By J. ARROWSMITH. Scale, 55 miles to an inch; size, 26 inches by 22. Sheet, coloured, 3*s.*; mounted, in case, 5*s.*

INDIA.—STANFORD'S NEW PORTABLE MAP of INDIA. Exhibiting the Present Divisions of the Country according to the most Recent Surveys. Scale, 86 miles to an inch; size, 29 inches by 33. Coloured, 6*s.*; mounted on linen, in case, 8*s.*; on roller, varnished, 11*s.*

INDIA.—MAP of INDIA. By J. ARROWSMITH. Scale, 90 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3*s.*; mounted in case, 5*s.*

CEYLON.—MAP of CEYLON. Constructed from a Base of Triangulations and corresponding Astronomical Observations. By Major-General JOHN FRASER, late Deputy-Quartermaster-General. Reconstructed by JOHN ARROWSMITH. Scale, 4 miles to an inch, size, 52 inches by 78. Eight sheets, coloured, 2*l.* 5*s.*; mounted, in case, 3*l.* 13*s.* 6*d.*; on roller, varnished, 4*l.* 4*s.*; spring roller, 6*l.* 16*s.* 6*d.*

CEYLON.—COFFEE ESTATES of CEYLON. Map showing the Position of the Coffee Estates in the Central Province of Ceylon. By J. ARROWSMITH. Size, 15 inches by 20. Sheet, coloured, 3*s.*; mounted, in case, 5*s.*

BURMAH, &c.—A Map showing the various Routes proposed for connecting China with India and Europe through Burmah, and developing the Trade of Eastern Bengal, Burmah, and China. Prepared under the direction of JOHN OGILVY HAY, F.R.G.S. Scale, 33 miles to an inch; size, 27 inches by 32. Coloured, 3*s.*; mounted, in case, 5*s.*

BURMAH and ADJACENT COUNTRIES.—Compiled from various MSS., and other Documents. By J. ARROWSMITH. Scale, 24 miles to an inch; size, 26 inches by 22. Sheet, coloured, 3*s.*; mounted, in case, 5*s.*

CHINA.—MAP of CHINA. By J. ARROWSMITH. Scale, 90 miles to an inch; size, 26 inches by 22. Sheet, coloured, 3*s.*; mounted, in case, 5*s.*

CHINA and JAPAN.—STANFORD'S MAP of the EMPIRES of CHINA and JAPAN, with the Adjacent Parts of British India, Asiatic Russia, Burmah, &c. Scale, 110 miles to an inch; size, 38 inches by 24. One sheet, full coloured, 8*s.*; mounted on linen, in case, 10*s.* 6*d.*; on roller, varnished, 14*s.*

AFRICA.

GENERAL MAP of AFRICA.—By J. ARROWSMITH. Scale, 260 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3*s.*; mounted, in case, 5*s.*

EGYPT.—MAP of EGYPT. Compiled from the most authentic materials, and founded on the best Astronomical Observations. By Colonel W. M. LEAKE, R A., LL.D., F.R.S. Scale, 10 miles to an inch; size, 34 inches by 52. Two sheets, coloured, 21*s.*; mounted, in case, 28*s.*; on roller, varnished, 36*s.*

EGYPT.—MAP of EGYPT: including the Peninsula of Mount Sinai. By J. ARROWSMITH. New Edition. Scale, 26 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3*s.*; mounted, in case, 5*s.*

AFRICA (NORTH-WEST).—MAP of NORTH-WEST AFRICA, including the Coast of Guinea, and the Isle of Fernando Po, on the South, and the Western parts of Egypt and Darfur, on the East. By J. ARROWSMITH. Scale, 130 miles to an inch; size, 26 inches by 22. Sheet, coloured, 3*s.*; mounted, in case, 5*s.*

AFRICA (SOUTH).—MAP of SOUTH AFRICA to 16 deg. South Latitude. By HENRY HALL, Draughtsman to the Royal Engineers, Cape Town. Scale, 50 miles to an inch; size, 34 inches by 28. Two sheets, coloured, 10*s.* 6*d.*; mounted on linen, in case, 13*s.* 6*d.*; on roller, varnished, 15*s.*

AFRICA (SOUTH-EASTERN). — MAP of SOUTH-EASTERN AFRICA. Compiled by HENRY HALL. Scale, 25 miles to an inch; size, 26 inches by 22. Sheet, 4*s.*; mounted on linen, in case, 6*s.*

AFRICA (WEST COAST).—MAP of the WEST COAST of AFRICA. Comprising Guinea and the British Possessions at Sierra Leone, on the Gambia, and the Gold Coast, &c. By J. ARROWSMITH. Scale, 50 miles to an inch. Two coloured sheets; size of each, 22 inches by 26. 6*s.* Mounted, in case, 10*s.*

CAPE of GOOD HOPE and SOUTH AFRICA—MAP of SOUTH AFRICA, Cape Colony, Natal, &c. By HENRY HALL. Scale 50 miles to an inch; size, 29 inches by 17. Sheet, price 4*s.* 6*d.*; mounted, in case, 6*s.* 6*d.*

CAPE COLONY (EASTERN FRONTIER).—MAP of the EASTERN FRONTIER of the CAPE COLONY. Compiled by HENRY HALL. Scale, 8 miles to an inch; size, 40 inches by 38. Sheets, 18*s.* 6*d.*; mounted on linen, in case, 25*s.*; on roller, varnished, 31*s.* 6*d.*

NATAL.—A MAP of the COLONY of NATAL. By ALEXANDER MAIR, Land Surveyor, Natal. Compiled from the Diagrams and General Plans in the Surveyor-General's Office, and from Data furnished by P. C. SUTHERLAND, Esq., M.D., F.R.S., Surveyor-General. Scale, 4 miles to an inch; size, 54 inches by 80. Coloured, Four Sheets, 2*l.* 5*s.*; mounted, in case, or on rollers, varnished, 3*l.*

NATAL.—MAP of the COLONY of NATAL. Compiled in the Surveyor-General's Office. Size, 11¼ inches by 14½. Sheet, coloured, 1*s.*; mounted, in case, 2*s.* 6*d.*

NUBIA and ABYSSINIA, including Darfur, Kordofan, and part of Arabia. By J. ARROWSMITH. Scale 65 miles to an inch; size, 26 inches by 22. Sheet, coloured, 3*s.*; mounted, in case, 5*s.*

AMERICA.

BRITISH COLUMBIA.—NEW MAP of BRITISH COLUMBIA, to the 56th Parallel North Latitude, showing the New Gold Fields of Omineca, the most recent discoveries at Cariboo and other places, and the proposed routes for the Inter-Oceanic Railway. Scale, 25 miles to an inch; size, 39 inches by 27. Price, in sheet, coloured, 7s. 6d.; or mounted on linen, in case, 10s. 6d.

CANADA.—MAP of UPPER and LOWER CANADA, New Brunswick, Nova Scotia, Prince Edward's Island, Cape Breton Island, Newfoundland, and a large portion of the United States. By J. ARROWSMITH. Scale, 35 miles to an inch; size, 40 inches by 26. Two sheets, coloured, 6s.; mounted, in case, 10s.; on roller, varnished, 15s.

UNITED STATES and CANADA.—STANFORD'S NEW RAILWAY and COUNTY MAP of the UNITED STATES and TERRITORIES, together with Canada, New Brunswick, &c. Scale 51½ miles to an inch; size, 57 inches by 36. Two sheets, coloured, 21s.; case, 25s.; on rollers, varnished, 30s.

UNITED STATES.—STANFORD'S HANDY MAP of the UNITED STATES. Scale, 90 miles to an inch; size, 40 inches by 25. Coloured sheet, 7s 6d.; mounted, in case, 10s. 6d.; on roller, varnished, 15s.

UNITED STATES.—STANFORD'S SMALLER RAILWAY MAP of the UNITED STATES. Scale, 120 miles to an inch; size, 29 inches by 17½. Two sheets, coloured, 4s 6d.; mounted on linen, in case, 6s. 6d.

CENTRAL AMERICA.—BAILEY'S MAP of CENTRAL AMERICA, including the States of Guatemala, Salvador, Honduras, Nicaragua, and Costa Rica. Scale, 8 miles to an inch; size, 40 inches by 27. Sheet, 7s. 6d.; mounted on linen, in case, 10s. 6d., on roller, varnished 14s.

MEXICO.—A GENERAL MAP of the REPUBLIC of MEXICO. By the Brigadier-General PEDRO GARCIA CONDE. Engraved from the Original Survey made by order of the Mexican Government. Size, 50 inches by 37. Sheets, price, 10s. 6d.; mounted on linen, in case, 18s.

BERMUDAS.—MAP of the BERMUDAS. Published by direction of His Excellency Major-General J. H. LEFROY, C.B., R.A., Governor and Commander-in-Chief of the Bermudas. Scale, 2½ miles to an inch; size, 62 inches by 63. Mounted, in case, or on roller, varnished, 21s.

WEST INDIA ISLANDS and GUATEMALA.—Showing the Colonies in possession of the various European Powers. By J. ARROWSMITH. Scale, 99 miles to an inch; size, 26 inches by 22. Sheet, coloured, 3s.; mounted, in case, 5s.

JAMAICA.—A NEW MAP of the ISLAND OF JAMAICA. Prepared by THOMAS HARRISON, Government Surveyor, Kingston, Jamaica, under the direction of Major-General J. R. MANN, R.E., Director of Roads and Surveyor-General. Scale, 2½ miles to an inch: size, 64 inches by 27. Mounted, in case, or on roller, varnished, 21s.

BARBADOES.—Topographical Map, based upon Mayo's Original Survey in 1721, and corrected to the year 1846. By Sir ROBERT H. SCHOMBURGH, K.R.E. Scale, 2 miles to an inch; size, 40 inches by 50. Two sheets, coloured, 21s.; mounted, in case, 28s.; on roller, varnished 37s.

AUSTRALASIA.

AUSTRALIA.—From Surveys made by order of the British Government, combined with those of D'Entre, Casteaux, Baudin, Freycinet, &c. By J. ARROWSMITH. Scale, 80 miles to an inch. On two sheets; size of each, 22 inches by 26. Sheets, coloured, 6*s.*; mounted, in case, 10*s.*

AUSTRALIA.—Constructed from Official and other original Documents, adjusted to the Maritime Survey of Flinders, King, Wickham, Stokes, Blackwood, Stanley, &c. By J. ARROWSMITH. Scale, 27 miles to an inch In Nine Sheets. [*Preparing.*

WESTERN AUSTRALIA.—With Plans of Perth, Fremantle, and Guildford. From the Surveys of John Septimus Roe, Esq., Surveyor-General, and from other Official Documents in the Colonial Office and Admiralty. By J. ARROWSMITH. Scale, 16 miles to an inch; size, 40 inches by 22. Two sheets, coloured, 6*s.*; in case, 10*s.*

SOUTH AUSTRALIA.—Showing the Division into Counties of the settled portions of the Province. With Situation of Mines of Copper and Lead. From the Surveys of Capt. Frome, R.E., Surveyor-General of the Colony. By J. ARROWSMITH. Scale, 14 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3*s.*; in case, 5*s.*

QUEENSLAND.—STANFORD'S NEW MAP of the PROVINCE of QUEENSLAND (North-Eastern Australia): Compiled from the most reliable Authorities. Scale, 64 miles to an inch; size, 18 inches by 23. In sheets, coloured, 2*s.* 6*d.*; mounted on linen, in case, 4*s.* 6*d.*

VICTORIA.—A NEW MAP of the PROVINCE of VICTORIA (Australia): Showing all the Roads, Rivers, Towns, Counties, Gold Diggings, Sheep and Cattle Stations, &c. Scale, 20 miles to an inch; size, 31 inches by 21. In sheet, 2*s.* 6*d.*; or mounted on linen, in case, 4*s.* 6*d.*

NEW ZEALAND.—STANFORD'S MAP of NEW ZEALAND: Compiled from the most recent Documents. Scale, 64 miles to an inch; size, 17 inches by 19. Full-coloured, in sheet, 2*s.*; mounted on linen, in case, 3*s.* 6*d.*

NEW ZEALAND.—From Official Documents. By J. ARROWSMITH. Scale, 38 miles to an inch; size, 22 inches by 26. Sheet, coloured, 3*s.*; mounted, in case, 5*s.*

NELSON and MARLBOROUGH.—A NEW MAP of the PROVINCES of NELSON and MARLBOROUGH, in New Zealand, with Cook's Strait, and the Southern Part of the Province of Wellington. Scale, 8 miles to an inch. Size, 40 inches by 27. In sheet, coloured, 7*s.* 6*d.*; mounted on linen, in case, 10*s.* 6*d.*

TASMANIA (Van Diemen's Land).—From MS. Surveys in the Colonial Office, and in the Van Diemen's Land Company's Office. By J. ARROWSMITH. Scale, 10½ miles to an inch; size, 22 inches by 26. Sheet, coloured, 3*s.*; mounted in case, 5*s.*

School Maps.

STANFORD'S NEW PHYSICAL SERIES OF WALL MAPS, for use in Schools and Colleges. Edited by Professor RAMSAY, LL.D., F.R.S. &c., Director General of the Geological Surveys of the United Kingdom.

Size, 50 inches by 58, mounted on rollers and varnished, each, 30s.

British Isles.	**Europe.**	**North America.**
England and Wales.	**Africa.**	**South America.**

Also, size, 34 inches by 42, mounted on rollers and varnished, each, 8s.

Scotland.	**Ireland.**

VARTY'S EDUCATIONAL SERIES of CHEAP WALL MAPS, for class teaching, constructed by ARROWSMITH, WALKER, &c. New and revised editions, coloured, mounted, and varnished.

The World in Hemispheres. Size, 51 inches by 26. Price 12s.

The World (Mercator). Size, 50 inches by 32. Price 10s.

The British Isles. Size, 51 inches by 41. Price 10s.

Also the following, each 6s. size, 34 inches by 28:—

Europe.	**Australia.**	**Journeyings of the Children of Israel**
Asia.	**England.**	**S. Paul's Voyages and Travels.**
Africa.	**Scotland.**	
America.	**Ireland.**	
New Zealand.	**Roman Empire.**	

VARTY'S LARGE OUTLINE MAPS. Price, in plain sheet, 2s.; coloured, 3s.; mounted on rollers, 7s.

The World (globular), 2 feet 3 inches by 4 feet 3 inches. Price, in plain sheet, 1s., coloured, 1s. 6d.

The World (Mercator), 21 inches by 15 in.

And the following, plain sheet, 1s. 3d.; coloured, 1s. 6d.; mounted on rollers, 4s., size, 2 feet 10 inches by 2 feet 2 inches.

Europe.	**America.**	**Ireland.**
Asia.	**England.**	**Palestine (O. Test.).**
Africa.	**Scotland.**	**Palestine (N. Test.).**

STANFORD'S OUTLINE MAPS. Size 17 inches by 14, printed on drawing paper. A Series of Geographical Exercises, to be filled in from the Useful Knowledge Society's Maps and Atlases. Price 6d. each.

STANFORD'S PROJECTION SERIES. Uniform in size, price, &c., with Stanford's Outlines.

The OXFORD SERIES of OUTLINE MAPS. Size, 16 inches by 14. Price 3d. each.

Scripture and Animal Prints.

PRECEPTIVE ILLUSTRATIONS OF THE BIBLE. A Series of Fifty-two Prints to aid Scriptural Instruction, selected in part by the Author of 'Lessons on Objects.' The whole from Original Designs by S. BENDIXEN, Artist, expressly for this Work. They have been recently re-engraved, and are carefully coloured. Size, 17½ inches by 13.

Price of the Work.

The Set of 52 Prints, in Paper Wrapper	52s.
—— in One Volume, handsomely half-bound	60s.
—— in Varty's Oak Frame, with glass, lock and key	60s.

Single Prints, 1s. each; mounted on millboard, 1s. 4d. each.

VARTY'S SELECT SERIES of DOMESTIC and WILD ANIMALS, Drawn from Nature and from the Works of Eminent Artists. In 36 carefully-coloured Plates, exhibiting 130 Figures. Size, 12 inches by 9.

The selection of Animals has been limited to those which are most known and best adapted to elicit inquiry from the young, and afford scope for instruction and application.

		Bound in Cloth.	In Frame and Glass.
Set of 36 Prints, Coloured	18s.	24s.	24s.
—— Plain..	12s.	17s.	18s.

Single Prints, coloured, 6d.; mounted on millboard, 10d.

The ANIMAL KINGDOM at ONE VIEW, clearly exhibiting, on four beautifully-coloured Plates containing 184 Illustrations, the relative sizes of Animals to Man, and their comparative sizes with each other, as arranged in Divisions, Orders, &c., according to the method of Baron Cuvier.

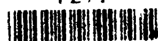
Exhibited on four Imperial Sheets, each 30 inches by 22:—

	Cloth, Rollers, and Varnished.	On Sheets.
Complete Set,		
Animals and Landscape, *full coloured* ..	58s.	18s.
Animals only coloured	35s.	15s.
Single Plates, *full coloured*	10s.	5s.

VARTY'S GRAPHIC ILLUSTRATIONS of ANIMALS, showing their Utility to Man, in their Services during Life and Uses after Death. Beautifully coloured. Size, 15 inches by 12. Price, the set, 31s. 6d.; in a frame with glass, lock and key, 39s. 6d.; or half-bound in leather, and lettered, 1 vol. folio, 42s.

The 21 separate Prints may also be had, price 1s. 6d. each.
Or Mounted on Millboard, 1s. 10d.

For complete lists of EDWARD STANFORD'S PUBLICATIONS, see his GENERAL CATALOGUE of MAPS and ATLASES, LIST of BOOKS, EDUCATIONAL CATALOGUE, &c., gratis on application, or by post for one penny stamp.


Y271